THE CONTRIBUTION OF ATOMIC ENERGY TO AGRICULTURE

HEARINGS

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY CONGRESS OF THE UNITED STATES

EIGHTY-THIRD CONGRESS

SECOND SESSION

ON

THE CONTRIBUTION OF ATOMIC ENERGY TO AGRICULTURE

MARCH 31 AND APRIL 1, 1954

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THE CONTRIBUTION OF ATOMIC ENERGY TO AGRICULTURE

WEDNESDAY, MARCH 31, 1954

CONGRESS OF THE UNITED STATES,
RESEARCH AND DEVELOPMENT SUBCOMMITTEE
OF THE JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D. C.

The subcommitteee met at 2 p. m., pursuant to call, in the caucus room of the House Office Building, Hon. Carl Hinshaw (chairman of the subcommittee) presiding.

Present: Representatives Hinshaw (presiding), Van Zandt, Durham, and Price; and Senators Bricker and Pastore.

Representative HINSHAW. The committee will come to order.

Our meeting today and tomorrow will deal with the uses and applications of atomic energy and especially radioisotopes in the field of agriculture. These are open hearings and in this respect are a refreshing departure from the closed-door approach which we have had to take in so many atomic-energy matters.

Although the military side of the atom gets most of the press headlines and catches the imagination of the public more easily, we believe that the peaceful uses of atomic energy may actually prove in the long run to be the most important for the individual citizen and for the world at large.

Atomic and thermonuclear weapons are vitally necessary to the preservation of peace but of more far-reaching significance is how we use the peacetime years which lie ahead. In that respect the president in quoting from the statement of Admiral Strauss, the Chairman of the Atomic Energy Commission, only this morning said in his final paragraph as follows:

> Finally, I would say that one important result of these hydrogen-bomb developments has been the enhancement of our military capability to the point where we should soon be more free to increase our emphasis on the peaceful uses of atomic power at home and abroad. It will be a tremendous satisfaction to those who have participated in this program that it has hastened that day.

Last summer the joint committee held several weeks of hearings on the prospects of using atomic energy as a source of electric power. Those hearings demonstrated that there are real future peacetime benefits to be gained from atomic energy. But the generation of electric power is only one area in which the atom can make large peacetime contributions.

There are other areas, such as the one we are here today to discuss, in which peacetime benefits are already here and growing rapidly. We are interested today in reviewing the progress and accomplishments to date in the uses of atomic energy in the field of agriculture.

If there are any ways in which the Atomic Energy Act can be amended in order to aid progress in this field, we want to find out

about them now. During this session of the Congress, we have every hope and intention of reporting out a revised Atomic Energy Act in response to the message from the President.

The country has a right to expect that any benefits which can be gained from atomic development will go forward unfettered by obsolete or unrealistic provisions of law. It is a pleasure, therefore, to begin these hearings in which both the Members of the Congress and the public will have an opportunity to become informed first hand from scientists who have been devoting their great talents to the agricultural applications of the atom. These gentlemen have come in from many parts of the country. They have interrupted vital and far-reaching work so that we may be better informed.

Before we call our first witness I would like to insert in the record at this point, the correspondence between Chairman Strauss of the Atomic Energy Commission and myself concerning these hearings.

(The correspondence referred to follows:)

CONGRESS OF THE UNITED STATES,
JOINT COMMITTEE ON ATOMIC ENERGY,
RESEARCH AND DEVELOPMENT SUBCOMMITTEE,
Washington, D. C., March 20, 1954.

ATOMIC ENERGY COMMISSION,
Washington, D. C.

GENTLEMEN: On February 4, the Research and Development Subcommittee held a meeting at which Dr. Bugher discussed the biology and medicine program of the Commission. At the conclusion of this meeting the committee requested that the Commission prepare a program devoted to the contributions of atomic energy to agriculture and that this presentation be made at a public hearing of the committee.

Since then the Commission staff and the committee staff have been working on the details for this program. I should therefore like to request that the Commission plan to make this presentation to the committee on Wednesday afternoon, March 31, and on Thursday afternoon, April 1. The meetings are scheduled for 2 p. m., and will be held in the caucus room of the Old House Office Building. The room has been reserved from Tuesday afternoon, March 30, through Thursday afternoon, April 1, in order that the Commission may have time to set up its suggested exhibits 1 day before the first hearing.

Dr. Paul B. Pearson of your office has furnished the committee with a copy of the proposed program and I wish to say that it will be most interesting and instructive to the general public and particularly to those of our citizens engaged in agriculture. In order that these hearings may be printed for the information of the general public promptly after the completion of the hearings I would like to request that the Commission make 8½- by 11-inch copies of all charts and other illustrative material used at the hearing suitable for reproduction.

Sincerely yours,

CARL HINSHAW,
Chairman, Research and Development Subcommittee.

UNITED STATES ATOMIC ENERGY COMMISSION,
Washington, D. C., March 29, 1954.

HON. CARL HINSHAW,
Chairman, Research and Development Subcommittee,
Joint Committee on Atomic Energy, Congress of the United States.

DEAR MR. HINSHAW: The Commission appreciates the interest of the Research and Development Subcommittee in holding a public hearing on the contributions of atomic energy to the field of agriculture. Pursuant to your letter of March 20, 1954, we have arranged a program by distinguished scientists in the field of agriculture. These men have been actively engaged in agricultural research in which atomic energy has contributed to major advances. In connection with the hearings, we have also arranged for a number of exhibits depicting some of the uses of atomic energy in the field of agricultural research.

We are pleased to know that you plan to print the hearings with illustrations for distribution to the general public. Our staff will be glad to work with the committee staff in providing prints, cuts, and other material that may be used in the printing of the hearings.

We understand from Mr. Edward L. Heller of the committee staff that you plan to invite the Senate Committee on Agriculture and Forestry and the House Committee on Agriculture to attend the hearings. We are glad to know that these committees are being specifically invited to attend as the hearings should be of particular interest to them.

Sincerely yours,

LEWIS L. STRAUSS, *Chairman.*

Representative HINSHAW. Gentlemen, I wish to welcome you here on behalf of the committee and all of those who stand to profit from what you have to tell us.

Our first witness will be Dr. John C. Bugher, Director of the Division of Biology and Medicine of the Atomic Energy Commission, who will discuss the scope of the AEC program as it relates to agriculture. Dr. Bugher is Director of the Division of Biology and Medicine, a doctor of medicine, graduate of the University of Michigan, and honorary science doctorate at Taylor University. He was professor of pathology at the University of Michigan until 1937 and staff member of the International Health Division of the Rockefeller Foundation since 1937.

He was engaged in research and control of infectious diseases, including work on the control of yellow fever in South America and Africa, and the control of other tropical virus diseases. He was director of the control and research in yellow fever at Bogotá, Colombia, in 1943, and he established and directed yellow fever research institute at Lagos in Nigeria. Research and publications in the field of pathology including cancer, yellow fever, and other virus diseases bear his name.

Dr. Bugher, will you step forward, please? We shall be delighted and honored to hear you.

STATEMENT OF DR. JOHN C. BUGHER, DIRECTOR, DIVISION OF BIOLOGY AND MEDICINE, ATOMIC ENERGY COMMISSION

Dr. BUGHER. Mr. Chairman and members of the committee, we are indeed honored by your invitation to appear before you this afternoon and relate the progress that is being made and that we expect to be made during the forthcoming years in the field of agricultural applications of atomic energy. This invitation comes at a singularly appropriate time.

During the past months with their portentous developments in nuclear weapons, there has been a great resurgence of questions as to our effectiveness in prosecuting the peacetime applications of atomic energy. Not only has this interest been concerned with atomic power for industrial purposes, but it has also been directed to the general field of medical applications, particularly in cancer research and therapy, and to the progress being made in agriculture.

The Division of Biology and Medicine of the Atomic Energy Commission is responsible for the protection of human life and health in connection with Commission activities, and for the extension of our fundamental knowledge of the effects of radiation on living things of all kinds. In the prosecution of this quest, therefore, we are directly

interested in all aspects of plant and animal physiology which bear upon the understanding of radiation effects and the mechanisms by which nuclear radiation may injure or may modify living structures.

Not only are we deeply involved in studies such as those conducted by the Atomic Bomb Casualty Commission in Japan and in the cancer research hospitals maintained by the Commission as well as in many research projects conducted in medical schools—all of these dealing with human problems—but our investigations extend deeply into animal and plant life as well as into the fundamental behavior of unicelular organisms and viruses. It is with the section of the program related to agriculture that we deal today.

The studies on the mechanisms of radiation injury to plant cells lead inevitably to fundamental questions of plant nutrition and the inheritance of plant characteristics, the latter forming a very important part of the science of genetics. That is the science of the inheritances of characteristics from one generation to another.

The prosecution of this research has involved, and will continue to involve, the development of new tools for the radiobiologist; new elements unknown in nature; new instruments with which to detect their presence and to measure the effects they produce. Here, as in the medical field, we have developed a large research organization which extends not only into the national laboratories, such as Brookhaven, Argonne, and Oak Ridge, but into nearly every major university, college, and agricultural research center of the United States and its Territories.

While the Commission has directed its main efforts toward the fundamental problems of radiobiology, it is gratifying to us that this work has found many applications in agriculture. Some of these you will hear more about today and tomorrow. The Commission has assumed that the Department of Agriculture and the State agricultural experiment stations are responsible for the research more directly related to agriculture.

It is clear that there can be no sharp boundary between the interests of the radiobiologist and the agriculturist. The observations of each are inseparably relevant to those of the other. An expression of this community of interest and responsibility is to be found in the combined program undertaken by the Division of Biology and Medicine and various branches of the Department of Agriculture and agricultural-experiment stations. Experiments that had their roots in a laboratory demonstration extend to practical situations through the research facilities and the experimental stations which have been such outstandingly fruitful components of the American agricultural scene for many years. While many of the research tools are unique and new, their application to far-reaching and fundamental problems of our agricultural economy is made possible by the work of many devoted people in Federal, State, and university agricultural centers throughout the past decades. In addition to the researches in which the Atomic Energy Commission participates, the Department of Agriculture and the agricultural experiment stations make extensive use of radioisotopes in their programs.

During these hearings we will strive to present to you a review of the impact of atomic energy on agricultural science today, and a survey of some of the outsanding accomplishments which have already been realized. As in all of the long-term applications of

atomic energy, we feel that the accomplishments of the present are but simple indicators of the potentialities which hold for the future.

Not only may we anticipate acceleration in our ability to increase agricultural productivity through more effective techniques of fertilization and cultivation, but also through the production of new strains of economically important plants resistant to disease or in other ways more adapted to the environment in which they must grow.

The major responsibility for the conduct of the Atomic Energy Commissions program in this area is carried by Dr. Paul B. Pearson, Chief of the Biology Branch of the Division of Biology and Medicine. He has been the center of the widely ramifying program of the Atomic Energy Commission that touches upon so many aspects of agriculture, and has been largely instrumental in organizing our agenda today.

Associated with us in these adventures are colleagues from the Department of Agriculture, Dr. Byron T. Shaw, Dr. Lyle T. Alexander, and Dr. Sterling B. Hendricks. Dr. Shaw is responsible for the Agricultural Research Service of the United States Department of Agriculture.

From various universities and colleges we have Dr. H. B. Tukey, head of the department of horticulture, Michigan State College, at East Lansing, Mich.; Dr. E. C. Stakman, professor of plant pathology, University of Minnesota; and Dr. J. C. Shaw, professor of dairy husbandry, University of Maryland. Dr. W. Ralph Singleton, geneticist of the Brookhaven National Laboratory, and Dr. Joseph S. Butts, Assistant Chief of the Biology Branch of the Division of Biology and Medicine, are more closely associated with the immediate program of the Atomic Energy Commission.

Dr. Shaw will develop the picture of the employment of radioisotopes in agricultural research in the great organization under his direction.

Thank you.

Representative HINSHAW. Thank you, Dr. Bugher.

Are there any questions you would like to ask, gentlemen? These other men are to be presented, I presume.

I might say that Dr. Shaw, while the Administrator of the Agricultural Research Service of the Department of Agriculture, took his bachelor of science degree at Utah State Agricultural College, and his doctor of philosophy degree at the Ohio State University, and he was a professor at Ohio State University in 1940 and 1943. The Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture, obtained his services from 1943 to 1947. Since then he has been the editor of Soil Physical Conditions and Plant Growth and research publications on soil physics.

Dr. Shaw, we are very glad to have you here.

STATEMENT OF DR. BYRON T. SHAW, ADMINISTRATOR, AGRICULTURAL RESEARCH SERVICE, UNITED STATES DEPARTMENT OF AGRICULTURE

Dr. SHAW. I appreciate the opportunity of discussing some of the ways in which nuclear fission is contributing to agricultural research.

The use of radioactive isotopes is enabling agricultural scientists to unlock a vast storehouse of knowledge about soils, plants, and animals. The radioactive tracer technique has already made possible significant advances in the science of plant nutrition. We have learned, for example, the phosphorus needs of various plants at different stages of growth and the efficiency of different phosphates. We are also using radioisotopes to great advantage in our studies on animal physiology and nutrition.

The Department's interest in radioactive materials as an agricultural research tool began long before radioactive isotopes were made available by the Atomic Energy Commission. In fact, almost 50 years ago a Department scientist, W. H. Ross, tested effects of radioactive materials on plant growth. Ross came to the Department from the University of Chicago, where he and H. N. McCoy had found two radioactive elements with which they were working to be chemically identical. Their finding was an immediate forerunner of the discovery of isotopes.

Between 1930 and 1940, when such great advances were being made in knowledge of nuclear phenomena, the Department had an active program on the study of stable isotopes. Interest centered on the small variation in the amounts of isotopes of potassium in plant materials. In 1940, radioactive phosphorous and sodium, which were produced in a cyclotron, were used to follow absorption into corn seedlings. The effects of ionizing radiations on plant growth were also studied. An interesting finding was the dormancy induced into Easter lily bulbs by a low X-ray dosage.

Isotopes that could be easily followed by radioactivity were hard to come by before 1940. All this has changed with nuclear fission. The nuclear reactor produces large quantities of isotopes that are of interest to agriculture. We can now use these isotopes to study nutrition of animals and plants, migration of insects, chemical changes in agricultural products, spray residues from insecticidies and herbicides, and numerous other problem areas.

Forty State agricultural experiment stations are working with isotopes at the present time, either individually or in cooperation with the Federal Department of Agriculture. More than 150 investigations that depend essentially on radioactive isotopes are underway. Among these are 35 dealing with soils and fertilizers, 29 with chemistry, and 16 with various aspects of animal husbandry. In addition to this extensive program being carried on by the States, the Department's Agricultural Research Service has a number of projects that involve the use of isotopes.

In three of the important dairy States, studies are being made of the way in which milk is formed in the cow. Radiocarbon is being used to trace acetate and other compounds circulated through the mammary gland and to trace glucose injected into the blood stream.

The cow, of course, as a ruminant, has peculiar problems of nutrition about which our concepts and practices are constantly changing. We are learning more, for example, about the supply of sulfur from herbage for milk and hair formation, about the supply of iodine for thyroid function, of cobalt for vitamin B_{12}, and of copper. The great interest in urea as a supplementary source of nitrogen for cattle encourages tracer work with a nitrogen isotope, which of course is the heavy one of mass 15. Urea is also being studied as a source of

nitrogen in spray applications to plant foliage. Radioactive isotopes are also being used by the State experiment stations to provide information on certain perplexing animal diseases, such as leukosis and Newcastle disease in poultry.

In the Agricultural Research Service, we have 15 active projects in which isotopes are used in research with insects. Radioisotopes are proving of great value as markers in following hibernation and migration of insects, and as tracers for insecticides, particularly the ones that are systematically taken in by plants.

In bee culture studies at Laramie, Wyo., we are using radiophosphorus to follow the spread of honeybee diseases by carriers between colonies. This isotope is also being used at Baton Rouge, La., to follow the feeding habits of bees. Migration habits of some of our worst insect pests are also being followed. These include the wheat-stem sawfly in Montana, the boll weevil in South Carolina, the pink bollworm in Texas, spruce beetles in Colorado, pine weevils in New York, and several insects in Oregon.

Scientists in one of the States are using radioisotopes in attempts to develop better solvents for insecticides applied to plants, which will coat the leaves evenly and yet not interfere with the absorption of the insecticides by the insects.

In animal nutrition and physiology work, we are using radioisotopes to study a variety of problems. Radioactive cobalt is used to study the function and utilization of vitamin B_{12} in sheep and chickens. Radioactive calcium and phosphorus are used to study the formation and metabolism of bone. Since all feed nutrients contain carbon, the radioisotope carbon 14 is especially useful in studying milk secretion, physiology of reproduction, growth of wool, egg production, and factors affecting the use of feed nutrients such as proteins, fats, and carbohydrates.

For years it has been assumed that nonruminant animals such as chickens and pigs cannot utilize sulfur in the inorganic form. Using radioactive sulfur, scientists in the Agricultural Research Service have recently found that the chicken can utilize inorganic sulfur and incorporate it into the amino acid cystine, which is one of the building blocks of proteins.

Five years ago, the Atomic Energy Commission and the Department of Agriculture began coperative studies on the use of radioisotopes in soil and crop research. The immediate objective of these studies was to find out what happens to radioactive materials reaching soil or plants. The ultimate purpose, of course, is to determine the steps to be taken in the event our farmland or food supply should be threatened by use of fissionable materials.

This question of reaction of the several isotopes in soil, and the passage of radioisotopes from soils or from the atmosphere into plants, is of major concern in agriculture. It is a part of our interest in the natural fertility of soils, in the correct use of fertilizers, and in the factors that play such an important part in the relationship of the plant to the soil in which it is growing.

Chlorosis of plants due to the immobility of trace elements, which is assumed to be the result of the formation of insoluble compounds within the plant, is being investigated by scientists in the Agricultural Research Service, and a number of the State stations. The movement of mineral nutrients in plants is also being studied by work-

ers at several institutions. They are using radioactive phosphorus calcium, sulfur, copper, molybdenum, and zinc, for example, in various plant nutrition studies. Tracing elements through living plants was impossible before radioisotopes were available.

Radioactive tracers are showing how conventional fertilizers can be used more efficiently and economically. American farmers are spending more than a billion dollars a year for commercial fertilizers. Isotope research has already found ways to get greater returns in crop yields from this money.

The isotopic tracer has proved very valuable in these studies. We can mark a certain material in the fertilizer, phosphorus, for instance, and tell how much moves into the plant. We can, therefore, compare two materials as to their efficiency in supplying the plant, without reference to growth response or confounding with climate. Or we can compare two placements, such as below the seed or broadcast. In this way, we are saving years in adequately evaluating fertilizer materials and methods of application. We are moving in cooperation with the States toward sound conclusions in fertilizer practices.

In fertilizer usage we want to know the amount and kind needed for best crop growth on the many types of soils. New fertilizer materials are being developed, and their value has to be measured. Quite naturally, requirements of a crop on a particular soil for a specific fertilizer have been measured by crop yield. But variation in rainfall and temperature, diseases, and other things also affect yield and confound the evaluation of the fertilizer. In the past, farmers have had to accept these crude estimates, but they need better answers, because fertilizer is often one of the largest cost items in producing a crop.

We can measure the capacity of the soil to supply a plant nutrient by adding a radioactive fertilizer as a partial source of the nutrient to a growing plant. The plant will draw upon both the natural supply and the added fertilizer, in a poor soil, most of the plant nutrient will come from the fertilizer. In a rich soil most of it will come from the soil.

The maintenance of soil fertility is one of the objectives of soil management. The soils of our Corn Belt are fertile. But how long will they continue, for instance, to supply adequate potassium to corn? We can measure this capacity to supply potash with radioisotopes. This time we do not use an isotope of potassium, for it has no isotope that is suitable. Instead, we use rubidium, which follows along with potassium almost as an isotope. The agronomists of the States realize the value of this method and are cooperating with the United States Department of Agriculture in its development.

You have probably noted that my comments have been restricted largely to use of radioisotopes. In the Agricultural Research Service we have not been so directly concerned with genetic and lethal effects of high-energy radiation, although, as I have indicated, some work has been done on genetic effects. We follow research in these fields with interest, however, for we, too, desire populations of greater variability for selection in plant and animal breeding.

We look forward to great modification in species, for economy in nutrition, marketability, and resistance to disease. We appreciate also the potentiality of lethal effects of high-energy radiation, both

from electron accelerators and from the radioactive products of nuclear fission, for sterilization of food products.

I feel that these uses of isotopes that I have mentioned are but a small part of their potential use in agricultural research. We are just beginning to learn how to use these new tools in our study of soils, plants, and animals. Every new discovery moves us one step nearer to our goal of learning how to make the wisest use of our natural resources and to make our agriculture more efficient.

Representative HINSHAW. Thank you.

Would any member of the committee like to question Dr. Shaw?

Representative DURHAM. Dr. Shaw, your address is rather technical as is the whole problem of radioisotope application. I am wondering what your opinion is in regard to the application to agricultural science, it is so highly technical.

Would it necessarily have to be handled by individuals who have a good deal of knowledge of radioisotopes, or do you think this will develop to a point where any ordinary farmer can use it?

Dr. SHAW. I doubt there will be applications that the farmers will be able to make. In other words, I doubt that the use of radioactive materials, say, as a fertilizer or anything of that sort will ever help the farmer. But the knowledge that the scientists gain in how a plant grows, or how an animal grows, and so on, is the important part of it. This knowledge will then be transformed into information that the farmer will make very much practical use of.

Representative DURHAM. You feel it is primarily a research tool and will be for many years to come?

Dr. SHAW. That is the way we feel.

Representative DURHAM. Now, the other thing you touched on there is the sterilization of foods. Can you elaborate a little bit on that, as to what you meant by that statement?

Dr. SHAW. There is research going on at the present time trying to sterilize food products while they are cold and thus avoid heating them like we do meat or other products with our current preservation methods. In other words, the object would be to hold the flavor, and all of the nutritional qualities of the fresh product that are now often destroyed by our methods of heating or dehydration or whatever methods of preservation we use.

Representative DURHAM. Would it have to be kept under certain conditions, perhaps under conditions of refrigeration?

Dr. SHAW. Well, the objective here is to achieve a method of sterilization that wouldn't require refrigeration.

Representative DURHAM. That will not require refrigeration?

Dr. SHAW. It would have to be canned after it is sterilized, or else during the time of sterilization it would be in a can, but it would not require refrigeration.

The study so far is promising, but they have no results as yet that would permit us to say that they are going to develop useful procedures.

Representative DURHAM. When you speak of useful procedures, of course, you think of whether or not you would grow a larger ear of corn or a small ear of corn, or what in your opinion would be the effect on the yield, in other words?

Dr. SHAW. You are going to have an explanation in a little while from Dr. Stakman and Dr. Singleton and others on the effects of the genetic variables in plants.

Representative DURHAM. That is all, Mr. Chairman.

Representative HINSHAW. Are there any other questions?

Dr. Bugher, is anyone going to discuss specifically that question of the preservation of foodstuffs by radioactivity?

Dr. BUGHER. Dr. Butts will present that material in his talk tomorrow.

Representative HINSHAW. That is a very interesting subject and we want to learn all about it that we can.

Mr. Dolliver, of Iowa, who is not a member of this committee, is present, and he wants to know what type of research in this field is being carried out at the Iowa State College at Ames, Iowa. Do you have information on that subject?

Dr. SHAW. I don't have specific projects in mind, but they are interested in most of the things we will be talking about, in plant nutrition and animal nutrition and so on. Their scientists are engaged cooperatively with all of the rest of us in most of these subjects.

Representative HINSHAW. Perhaps Dr. Pearson could give us some information on that subject.

Dr. PEARSON. We do have 3 or 4 projects that we are supporting in Iowa State College. One is a project on genetics in mice, and we are starting out with a laboratory animal with the expectation that some of these findings might be extended to large animals, that is farm animals of economic importance.

We are also supporting work on the metabolism of nucleic acids which make up a part of the genetic factors which are responsible for characteristics of both animals and plants. I believe there are 2 or 3 other projects, and the titles of them I don't recall. We have one on root growth, how roots absorb various plant nutrients, and transport it into the root of the plant and actually utilize it, and I believe there are 1 or 2 others.

Representative HINSHAW. Thank you very much, Dr. Pearson.

We are very appreciative of your presence today, Dr. Shaw, and you have given us a very fine view of the situation in respect to the use of isotopes in experimental stations.

Thank you.

Now, we are to hear from Dr. Sterling B. Hendricks, the head chemist at the Soil and Water Conservation Branch of the Agricultural Research Service, Department of Agriculture. He is to give us some information on the subject of photosynthesis, and the effect of light on plants. That is a very absorbing subject, Dr. Hendricks, and we are very much interested to hear what you have to say. I might add that Dr. Hendricks received his bachelor of chemical engineering degree at the University of Arkansas, and his master of science degree at Kansas State College, and his doctor of philosophy at California Institute of Technology, and his honorary doctor of laws at the University of Arkansas. From 1927 to 1928 he was on the staff of the Rockefeller Institute for Medical Research.

He has been with the United States Department of Agriculture since 1928. He is the recipient of the Hildebrand award of the American Chemical Society for work on crystal structure.

He is a fellow of American Society of Agronomy, and a member of the National Academy of Science.

Research and publications on constitution of soils, structure of matter, light, and plant growth and the metabolism of plants are to his very great credit.

Representative DURHAM. You left out one thing, Mr. Chairman. He is a great mountain climber.

Representative HINSHAW. He and Justice Douglas then have something in common.

We are delighted to have you here, Dr. Hendricks, and we will be more than happy to hear what you have to say, especially since the subject of photosynthesis is such an important one to humanity.

STATEMENT OF DR. STERLING B. HENDRICKS, HEAD CHEMIST, SOIL AND WATER CONSERVATION RESEARCH BRANCH, AGRICULTURAL RESEARCH SERVICE, UNITED STATES DEPARTMENT OF AGRICULTURE

Dr. HENDRICKS. Thank you very much, Mr. Chairman. I must express my appreciation to you for the invitation to appear before the committee, and to tell you something about photosynthesis and something in general about the action of light on plants.

I will read about three paragraphs, and then I will discuss the aspects of it.

Photosynthesis, the subject which I wish to discuss, is of interest for two main reasons here. The first of these is that certain very great steps forward have been made by use of radioisotopes toward an understanding of the way in which photosynthesis takes place. The second is that photosynthesis has led to all of our fossil fuels, such as coal and oil.

Photosynthesis, of course, is the basis for all life in that animals eat plants. It is the process through which the radiant energy from the sun is stored in chemical energy of plants. We should not forget, however, that the primitive sources of the energy are the nuclear reactions that take place in the sun. It is often lost sight of, but the primitive sources of energy are themselves nuclear reactions of the sun.

Since it appears that our future well-being depends first, upon use of nuclear energy sources as fosil fuels are exhausted, and second, upon the continued production of food by the basic process of photosynthesis, it will be of interest to examine the nature of photosynthesis in detail.

Now, I have a chart here, and plants showing some of the phenomena. I will discuss the chart at this time. This particular chart was reproduced in a publication of the Interior and Insular Affairs Committee of the House of Representatives. It does not have a number, but was put out by that committee about 2 years ago following an investigation on the energy sources within the United States. (See exhibit 1, p. 12.)

Dr. HENDRICKS. Now, the process of photosynthesis is divided into three essential stages. As shown in this schematic diagram from the publication. The first stage is the receipt of the energy from the sun. The sun falls upon the plant and upon the green leaf, and the rest of the things take place within the leaf. We hope to indicate here what some of those specific processes are.

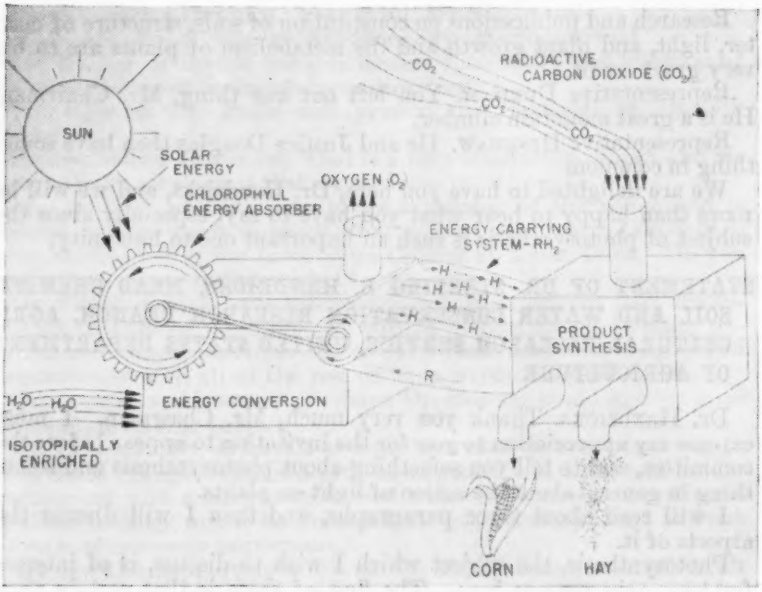

EXHIBIT 1.—Photosynthesis—energy, principal raw materials, and products.

The sunlight falls, as indicated in this mechanical picture, upon the leaf. It is the energy that is absorbed in the leaf, and, of course, in the leaf it is no longer there in form of radiation; instead it is immediately changed into some form of chemical energy.

Now, within the plant, water is also present, and one of the first acts that takes place is a reaction involving the water. The hydrogen derived from the water is transferred to other materials and these materials finally react with the carbon dioxide from the air to form the product of the plant and form the entire plant, the fruit of the plant; if it is a corn plant, an ear of the corn, or it it is a grass plant, the foliage of the grass.

Now, I want to show you specifically how several of these steps have come to be known and the way in which isotopic tracers in particular have helped to find out specifically what is going on.

The light falling from the sun upon the plant is absorbed by the pigment, which is present in small bodies. These colored poker chips represent plastid that are present in the plant. The plastids are just on the limits of microscopic visibility. They are little flat bodies like the poker chips which would be roughly a ten-thousand-fold magnification of the plastid.

The chlorophyll, which is the green coloring matter of the plant, is the first pigment that absorbs the radiation from the sun. It is spread in a thin layer over the surface of this plastid. The plastids are grouped together in a little sack, in a little cellular membrane. The

plastid to the plant is roughly like the red blood cell is to the animal, or to the human being. It is formed at the time of formation of the leaf, and as the leaf grows the plastid increases in size.

But many of the characteristic features of the plastid have to be there at the time of its formation, and by the use of radioactive iron you can see the iron has to be present in the plastid at the time of its formation. That is also true for the formation of the red blood corpuscle in the human being. The hemoglobin cannot form in the red corpuscles after the corpuscle is formed, but it all has to be assembled at one time and then it has a certain lifetime as does the chlorophyll in the plant.

Now, the light is absorbed at one point on the plastid and it is there changed into excitation energy of the pigment, of the chlorophyll, and that can wander around over the plastid and come over to some point like this where it causes a chemical reaction to take place.

So the first entry of radioisotopes into this was to learn firstly some characteristics about the formation of the plastid, and secondly some characteristics of the permeability of this membrane on the plastid, that potassium cannot move in and out as it does through the red blood cell.

Now, then, the second step is that this chemical energy has to go through some changes and it has to be stored to be of future value to the plant, and in its future value to the plant to be of use to man.

It was not until 1940 that one could definitely show something about the role of water in the process of photosynthesis. One knew that oxygen was evolved during the process but the oxygen might have come from cardon dioxide or it might have come from water. At that time workers at the University of California using the heavy isotope of oxygen, oxygen of mass 18, found that if that isotope was placed in the water, the oxygen that was involved was enriched in that particular isotope and if it was placed in the carbon dioxide, the oxygen was not enriched. So it followed that the source of the oxygen was the water which was logical in the sense then that it leaves the hydrogen free to be transferred in a chemical reaction, and the hydrogen is so transferred.

Now, it is wise in studying life processes insofar as possible to take them apart in stages, bit by bit, to avoid some of the complexity of the total. This stage then has in part been taken apart and isolated. Now, workers in Cambridge University in England were successful in taking out this next stage, and they found that if you ground up the leaves of a plant and thereby destroy the photosynthetic process as a whole, and nevertheless isolated the individual plastids from the plant, that these plastids in water, when light fell upon them, would still carry out the reaction of evolution of oxygen and transfer hydrogen to something, but they would not transfer hydrogen to carbon dioxide which is the process that is necessary for photosynthesis.

So that is where matters stood roughly in 1940.

After the war, in 1945, when carbon 14, the radioactive carbon became available through the facilities of the Atomic Energy Commission at Oak Ridge, Tenn., workers at the University of California

associated with Prof. Melvin Calvin began work upon the specific process that goes on in the chemical reactions of carbon dioxide after the hydrogen is transferred into the system. That is a stage at which immense progress has been made.

There are two very interesting questions about that. The two interesting questions are: What is the first product that carbon dioxide forms in the plant? And the second is, What is the detailed pathway by which sugar or cellulose as the ultimate product, is formed within the plant?

The first of those questions, what is the first product, has proven to be singularly difficult to answer. I will start with something like one of the last products.

Here is a plant, and this plant is from my own backyard and it is a sedum spectabilis, a sedum plant, and it has the interesting characteristic that it contains the sugar sedoheptulose, which is a 7 carbon sugar, whereas most of the sugars are 6 or 12 carbon sugars.

A worker in the Department of Agriculture in 1912, Dr. LaForge, when he first came to work, asked the man under whom he was to work, what would be his first task. They were in their backyard at that time, and the man in charge kicked this particular plant and he said, "Oh, isolate the sugar from it. It is of no importance, but it would possibly be rather interesting to locate." He did that, and it turned out to be this 7 carbon sugar.

Well, up to that time only 6 carbon sugars had been found and everyone was convinced that there were only 6 carbon sugars, and so Dr. LeForge told me that for the next 3 years he had a very difficult time keeping his position because it seemed obvious that he wasn't a very good man.

But now this 7 carbon sugar turns out to be the key of almost everything. It is the key to the pathway of photosynthesis, this sedoheptulose. After the discovery that it was the key to the pathway of photosynthesis it was discovered that it was an extremely important link in the life of a human.

Specifically, there are two ways of degradation of glucose in the human body. One of those goes down through what we call fermentative systems, that generate carbon dioxide, and go down through 6 carbon sugars through glucose down to 3 carbon sugars. Then, finally to carbon dioxide and water.

However, there is another pathway that is followed, and has been discovered now with the appearance of sedoheptulose. It is one in which the glucose goes first to a 5 carbon sugar, and then 2 carbons are added to it to form this particular sugar. This material is the source of a large number of the intermediate products that are involved in the nutrition of man.

The important thing in the nutrition of the plant is that the first product is already more complicated than carbon dioxide. One of the first things that one notes appearing in relatively large amounts is this 7 carbon sugar. This 7 carbon sugar apparently splits and gives rise to a 5 carbon sugar and a 2 carbon compound. That is a 2 carbon fragment, and this fragment goes back and it is the thing that reacts

with the initial carbon dioxide, as a matter of fact, the 5 carbon fragment is also involved.

You see, first they split into 5 and 2 and the 2 went back and got another carbon dioxide and took it up to the 7, and again split to 5 and 2, and came back. The 5 also splits to 3 and 2, and the 2 goes back, and gets another carbon dioxide and comes up to 7 and splits to 5 and splits to 3 and 2, and the 2 gets another carbon dioxide and goes up again.

It is a very fast process, and the process of life apparently depends upon interkeying a tremendous number of things simultaneously. If you analyze the products that arise from several seconds of fixation of carbon dioxide in the plant, you will already have of the order of 10 compounds that can be isolated and identified.

So through the use of radioisotopes, and particularly most recently in the hands of Professor Calvin, the processes that go on in the change of carbon dioxide are reasonably well understood. What is not understood is how one can couple the other parts of the system together.

There is also another thing. The process is strikingly inefficient. It is really a quite low efficiency. While in general we cannot change too greatly the processes of life—they go on without too much modification on our part—nevertheless, since this efficiency is so low, we would hope to find methods whereby we can obtain a higher efficiency than that.

This is not the only way in which light interacts upon a plant. I would like to show you one other method in which light acts upon a plant to show the importance of light in the control of plant growth, and specifically in the end to show you how use of an isotopic tracer promises to solve this particular question.

Here are some bean plants that were planted in darkness. They are 5 days old at the present time. They have been out here since morning and already they are beginning to green up slightly. That shows how fast that particular reaction goes. This internode is quite long. The leaf is small. All of those things about the plant are changed if a litle bit of light hits it. The question is how does that process take place.

Here is another display of that same phenomenon. If you plant a cornseed, far beneath the surface of the ground, it will elongate until it hits the surface and there it will put out its prop roots. In other words, the corn has a method of recognizing the presence of light.

Here are corn seedlings that were planted in that way—two seeds that were planted at some depth beneath the surface of the ground. You will note that here was the position of the seed, and here are the prop roots. This seed was planted this deep, and elongated about 2 inches to there, and put out its prop roots. This was planted at the surface and the length of the node now is only a fraction of an inch.

The plant had some method of recognizing the presence of light. This shows the phenomenon in another way. Here is a weedseed. This is peppergrass. In this case the seeds were placed on the surface of the soil. They all germinated. Here they were covered with one-eighth of an inch of soil and none of the seed germinated. In other words, there was something characteristic of the presence of light in the germination of the seed.

Similarly the flowering of plants, such as the chrysanthemum there, and the barley plant here are also influenced. These barley plants are the same age. This was grown under winter conditions and is vegetative, and this is grown under summer conditions and has a spike. The difference is the action of the light, the length of the day upon this particular plant.

The question is, what are these processess of growth control by light and when one examines them carefully, he comes out with the answer that all of those processes in the plant are controlled by the action of the plant-growth hormone which we call auxin or indol acetic acid. Indol acetic acid is an indol derivative, a material of feces, and acetic acid as in vinegar, as you know. The combination of these two leads to indol acetic acid. It is the indol acetic acid combining with some pigment in the plant, as yet undiscovered, which controls this action. To date no one has isolated the compound.

Here is how a problem of that nature is attacked. If the compound is present in too minor an amount to determine by its isolation, you then prepare the compound as a radioactive material. You put a carbon 14 into the indol acetic acid. That makes it simpler to isolate. You put some radioactive indol acetic acid upon the seed or into the plant, and then you attempt to isolate the specific material with which it combines.

There are 2 places in the United States, 1 in California and 1 in Illinois, at which efforts are being made to find out what the compound is with which indol acetic acid combines. It is as fundamental for the growth of the plant as the process of plutosynthesis.

Similarly the compound coumarin, which you will recall is the material that was recently forbidden by the Food and Drug Administration to be used in food materials. It had previously been used largely in vanilla extracts and similar materials. Coumarin, too, has exactly the same effect upon plants, in part upon seed germination, as this other.

I would be glad insofar as I can to answer any questions that I might on either aspect of this.

Representative HINSHAW. Dr. Hendricks, I have one question. I understand that Dr. Calvin has succeeded in synthesizing most of the steps in photosynthesis.

Dr. HENDRICKS. Yes.

Representative HINSHAW. You say he and others still are unable to synthesize this—is it 1 step or 2 steps?

Dr. HENDRICKS. The first step. The two carbon molecules to which the carbon dioxide is attached is still to be cleanly identified.

Representative HINSHAW. Is that the one step?

Dr. HENDRICKS. That is the first step.

Representative HINSHAW. Or is it the only step that they have not yet synthesized?

Dr. HENDRICKS. No, there are many others. There are several others along the way. One might say that there are 10 essential steps and one would say that 6 of those are probably known. That would be a good estimate. But those six give the cleancut pattern of what is taking place.

I can indicate to you the reason why they have been unable to discover the two carbon fragment. That in itself is an interesting reason. It is this sort of a reason. In many of the processes of life,

a material is on its way through a system. It is like an express train. The express train passes through the place. It does not give off any of the materials, and although you know it has gone through, you cannot characterize it. Sometimes the two carbon fragment has to be carried in an active form. The moment you get it out then it immediately has reacted with something else. It is the difficulty of getting out that active form that has prevented its isolation. By determining what finally goes in there, you can say pretty clearly in the end what it is and Professor Calvin can say with a moderate degree of precision what that is. What he has said is that the first product that is recognized that comes out is the three carbon phosphoglyceric acid.

Representative HINSHAW. What will be the benefit—I ask you for the sake of the record—if all of these steps of photosynthesis can be imitated or can be synthesized by chemical processes or chemical and light processes?

Dr. HENDRICKS. There are two types of ambitions and they are long range ambitions. It is the ambition of some completely to get around the use of the plant at all, namely, to find processes which you could cause to run to utilize solar radiation and possibly chlorophyl. If you understood the process in the plant perfectly, maybe you could devise another one that made it unnecessary to use a plant to store energy in the chemical form from sunlight.

The other is, as indicated, the process is largely inefficient and it would be our hope that if at one stage or the other we could find the limiting factor that we could then operate more clearly on removing that limiting factor.

I would like to indicate what the limiting factor probably is. Plants go to sleep in the middle of the day. They stop photosynthesizing. They just quit. The usual statement about that is there is a narcotic that the plant forms. That covers our ignorance of the situation, you understand. Something happens inside the plant that stops the process itself. If by understanding the details of the process we could know the step at which it stopped, perhaps we could get around the limiting factor.

So those are the two specific ambitions.

Representative HINSHAW. I would presume that if they could synthesize all of these steps that they would be able to provide synthetic foodstuffs—that is organic stuffs—from inorganic stuffs.

Dr. HENDRICKS. Yes, from carbon dioxide, water, and sunlight.

Representative HINSHAW. Which would mean they could themselves create the human foodstuffs or animal foodstuffs.

Dr. HENDRICKS. Yes, sir.

Representative HINSHAW. That is one of the ambitions of some of these research people, including yourself, I understand.

Dr. HENDRICKS. Yes, sir.

Representative HINSHAW. That we could relieve thereby any prospect of suffering from lack of sufficient soil on which to grow things when the population of the earth gets very large.

Dr. HENDRICKS. Yes, sir.

Representative HINSHAW. Any questions? If not, thank you. That is a very interesting discussion, Dr. Hendricks, and I think the committee will want at some time to visit the laboratories that are engaged in that research, and have a more detailed discussion of the

processes and syntheses and also meet some of the people that are engaged with you in that undertaking.

It is vitally important to the human race as a whole and can be of the utmost importance in providing foodstuffs for the sustenance of life itself.

Dr. HENDRICKS. Thank you.

Representative HINSHAW. Dr. Lyle T. Alexander, soil scientist of the Soil Conservation Service, Department of Agriculture, will discuss radioisotopes in fertilizer and plant study. He obtained his bachelor of science degree at the University of Arkansas, his doctorate of philosophy at the University of Maryland. He has been the United States delegate to the International Soil Science Congress in Helsinki in 1938. He was the head of the International Mission for Study of Soil Problems in Central and West Africa in 1951. He has issued many publications on research on soils and fertilizer.

Dr. Alexander, we are honored to have you present today, and to discuss with us this very important subject.

STATEMENT OF DR. LYLE T. ALEXANDER, SOIL SCIENTIST, SOIL CONSERVATION SERVICE, UNITED STATES DEPARTMENT OF AGRICULTURE

Dr. ALEXANDER. Thank you, Mr. Chairman. I, like the others, consider it a privilege and an honor to be permitted to come before this committee and say something about our work.

In order to conserve time, I shall read a short statement we have here, and then I will discuss some of the charts that I have on the easel up there.

The use of radioisotopes in soil, fertilizer and plant nutrition research antedates the Atomic Energy Commission and the Manhattan project. Papers on these subjects were published in 1939 from the University of California and in 1941 from the University of Hawaii and Purdue University. The sources of the radioisotopes in these early studies were the cyclotrons of the University of California at Berkeley and at Purdue University in Lafayette, Ind. However, the amounts of materials available from these sources were small. The principal purpose of the cyclotron was that of fundamental research in the fields of nuclear physics and chemistry.

When the Atomic Energy Commission made available large quantities of a variety of radioisotopes through the facilities at Oak Ridge, the bottleneck holding back general use of radioisotopes in soil and fertilizer research was broken. In 1947 there were a few field scale experiments with the radioisotopes of phosphorus cooperative between the United States Department of Agriculture and a few State agricultural experiment stations. Four crops were involved. One year later these soil and agronomic workers had field experiments involving 10 crops in 5 States. Greenhouse and laboratory research also were expanded.

The large scale use of tagged isotope fertilizers was made possible by the establishment at the plant industry station, Beltsville, Md., of adequate facilities for producing fertilizers tagged with phosphorus. This facility obtains neutron irradiated phosphorus compounds from Oak Ridge National Laboratory and in turn prepares the desired radioactive fertilizers for use by other agricultural

research service workers and for the use of State agricultural experiment stations and other qualified agricultural research institutions.

During 1953, this plant of the Fertilizer and Agricultural Lime Section of the Agricultural Research Service processed 88 units (31 grams each) of potassium phosphate from Oak Ridge. This amount is equivalent to 19 grams of radium in so far as radiation is concerned. These 88 units tagged 285 pounds of P_2O_5 in fertilizer form. These fertilizers were packaged in 2,500 weighed portions and dispatched in 50 shipments to 30 different receivers in 20 States, 2 Territories and 1 foreign country.

Dr. Shaw has indicated to you the extent of the use of radioisotopes in the United States Department of Agriculture and in the various State agricultural experiment stations. I would like to tell you very briefly the way in which a tagged atom, in this case a radioisotope, works and I will cite some specific examples of findings of importance to agriculture that have been made with an assist from the radioisotope.

In the concentration used in soil and fertilizer experiments the radioactive isotope of an element does not behave differently, insofar as the soil and plant are concerned, from its nonradioactive brother. Because of its instability, however, a certain percentage of these radioactive atoms disintegrate or change to some other element with the release of energy in the form of alpha, beta, or gamma rays. This energy can be readily detected by suitable instruments. This is the "tag" which I have referred to.

The use of the tagged element in fertilizer research is based on a dilution principle. It is analogous to a method that is used for determining the number of fish in a pond which are of a given kind. One releases 100 fish in the pond which have a fin missing or have a clip in their tail. After sufficient time for all of the fish to get mixed or equilibrated a sample is taken with a seine or by hook and line. Now if we remove 100 fish and find that only 10 of them are marked, then we know that our fish have been diluted with 9 times the number we put in the pool. Thus, there were 900 of this kind of fish in the pond.

With this digression as a background I will cite some accomplishments facilitated by the radioisotope tool. In some classes it might have been possible to get these results by other methods. But the process would have been more expensive in terms of time and money. In many cases the results would not have had the same degree of reliability.

EVALUATION OF FERTILIZER AND LIMING MATERIALS

In the past the value of a new fertilizer material has been judged by making comparisons btween yields of crops produced by soil with and without it or by determining relative yields obtained when the material is compared with a standard accepted product as a reference. In order to obtain reliable values by this method it is necessary that the soil used give a yield response great enough to produce relative large increases for the fertilizer application. This is due among other things to inherent variability in plants when used as an assay tool.

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Although yield responses are a satisfactory and in some cases a preferable measure, the new technique permits evaluation under conditions where no increase can be obtained—for example, adverse climatic conditions or high fertility levels. The plant can still judge the availability of the fertilizer material in question in the following manner. The extent of the presence of the tagged fertilizer atoms in the plant gives a measure of the availability to it. When two or more tagged sources of phosphorus, for example, are added in the same way to comparable plots of soil, their comparative availabilities to the plants grown are proportional to the extent of the appearance of the tagged atoms in the crop. It is apparent that this method permits the evaluation of the role of the fertilizer at any stage of the plant's growth throughout the season. Many State agricultural experiment stations and the Agricultural Research Service have participated in an evaluation of various new and standard phosphatic materials by this method during the last few years. The Agricultural Research Service has also used this method to determine the reaction rates of a number of limestone and furnace slag materials when used to combat soil acidity. Many agronomists may still prefer to see a yield response in a fertilizer trial. Too, this is the kind of evidence that is most convincing to a farmer. But we do now have methods of comparing availability of fertilizers on soils and under conditions where we could not have made an evaluation in the past.

MEASUREMENT OF THE GROWTH AND ACTIVITY OF PLANT ROOT SYSTEMS

A recent bulletin, Technical Bulletin No. 101, North Carolina Agricultural Experiment Station, reports the results of studies made on the growth and activity in nutrient uptake of the root systems of corn, cotton, peanuts, and flue-cured tobacco. Radioactive phosphorus from Oak Ridge was used as injections into the ground at various positions with respect to the base of the plants. The elapsed time and appearance of the isotope in measured quantities in the plant permitted the making of a detailed pattern of the progress of root penetration and fertilizer absorption as the plant grew. It also made possible a determination of the contribution of each zone of the root system to the phosphorus nutrition of the plant.

The publication is well illustrated with colored sketches on pages 10 and 11 for corn; 14 and 15, for cotton; 18 and 19, for peanuts; and 22 and 23, for tobacco. Pronounced differences between crops are noted. Corn with its extensive root system during and subsequent to the period of maximum growth cannot get a major share of the phosphorus needed to make a crop from application made at planting time. You will note there that the roots for the corn are predominantly below the plow depth when it comes toward maturity of the crop. The crop is made largely from the phosphorus that was already present in the soil. However, applications near the seed at planting time can be very helpful in getting the young corn plant off to a vigorous start. Many times it has been noted that applications of phosphorus fertilizers to corn at planting time show increased growth during the earlier stages but fail to materialize an increased yield of grain at harvest time. The data given in this North Carolina bulletin give an explanation for this behavior.

Other interesting points are the comparatively shallow feeding of cotton and the heavy uptake of nutrient immediately beneath the peanut plant during the first 7 weeks of growth.

Aside from information on the application of fertilizers data of this kind throw light on time and depth of supplemental irrigation which is becoming important in the production of high acre value crops such as tobacco, even in areas of rather high total annual rainfall.

Research of this kind will lead to a better understanding of the volume of soil utilized by the various crop plants under ideal conditions. In our soils of the Southeast which were naturally low in fertility, we ask the plants to make out on the nutrients applied in the top 6 inches or plow depth. Perhaps it may be possible to raise the ceilings on our yields by providing a deeper zone of nutrients more in keeping with what the plant would like to have. If heavy rooting could be induced in a number of our crop plants to the extent of 1 additional foot depth, it would go a long way toward elminating the bad effects of droughts of relatively short duration. Fundamental research on rooting characteristics in relation to soil properties may show the way. If this research is carried out, radioisotopes will certainly play a prominent part.

DETERMINING THE FERTILITY STATUS OF SOILS

The consumption of fertilizers in the United States and its territories in fiscal year 1952–53 amounted to 23.1 million tons. You are aware of the role it plays in producing our abundance of agricultural products. Its cost takes a considerable bite out of the gross income of many of our farm families. In order for the farmer to make the best use of his fertilizer dollar he must know the needs of the crops which he is growing and the fertility status of the soils on which he is growing them. There are two specific instances in which the use of the radioactive isotope of phosphorus has made a contribution to improving our understanding and use of fertility tests for the individual farm field.

One of these developments is really the counterpart of the fertilizer evaluation method which has already been mentioned. When a plant is presented with two sources of a given element at the same time, phosphorus in this case, it will absorb from each in direct proportion to the amounts available. One of these sources is the fertilizer and the other is the soil. As pointed out previously, the extent to which the tagged fertilizer atoms appear in the growing plant gives a measure of the contribution of the fertilizer to the growth of the plant. Conversely, the extent of the dilution of the fertilizer phosphorus in the plant is a measure of the availability of that element in the soil. The State agricultural experiment stations and the Agricultural Research Service have contributed to the development and use of this method of evaluating the phosphorus availability of soils.

Work of the Agricultural Research Service headquartered at Fort Collins, Colo., and cooperating with the western State agricultral experiment stations has resulted in a greatly improved fertility test for use in neutral and alkaline soils which predominate in that area. It is the outgrowth of some fundamental research on the specific surface of ionizable compounds such as soil and phosphatic materials. The measurement depends upon an equilibration between the radio-

active atoms of phosphorus in a solution and nonradioactive ones of the solid surface. Again, the extent of the dilution of the radioactive ions in the solution measures the phosphorus on the solid surface. Experiments with a number of western soils show that this surface measurement of available phosphorus agrees more closely with actual uptake in greenhouse plant growth studies than does any other laboratory procedure that has been devised.

Most of my illustrations have been taken from the work that has been done with radioactive phosphorus. This is for the reason that more solid accomplishment can be cited and the examples are easier to present. However, work is under way with other elements including calcium, sulfur, zinc, iron, and cobalt. Nitrogen does not lend itself to the radioactive approach but there is a stable isotope that is being used in a manner identical with that I have outlined, except that a mass spectrograph is used for the measurement instead of a radiation activated instrument. Potassium does not have a radioactive isotope of suitable half life for fertility studies but investigations are under way which will determine to what extent rubidium, a similar element that does have an isotope of suitable half life, can be used to evaluate potassium behavior.

In conclusion, it is my opinion that the radioisotopic technique opens many new fascinating vistas in soil, fertilizer, and plant research. It adds to the precision and reliability of many of our measurements which are of importance to American agriculture. It does not replace or make obsolete our current research methods and procedures, but rather supplements them as a very useful new tool.

I would like to show you my illustrations over here. Dr. Shaw mentioned the matter of chlorosis. We have here a soybean plant developed in Iowa (see exhibit 2, p. 23) that is particularly susceptible to this chlorosis on calcereous soils. This is the bottom of the plant and this is the top half of the same plant. When that plant grew these two green leaves here, it then became chlorotic and probably grew these from iron that was in the seed. Then another kind of plant from a different soil and not chlorotic was grafted over here, and that top cut off. Then this plant, when it had access to the iron produced by this root system, grew these sets of green leaves here. Then they cut this root off again and left it on the original root system, and then it produced these three yellow leaves. The radio audiographs here show that. Here are the six leaves that came on while it was getting its iron through this root, the soybean that could get it. Mind you, these were both in the same soil with their roots intermingled. Then it was cut off and you can hardly see these three leaves right in here, very short on iron, and quite yellow when they did not have this root system to do the work for them.

This over here (see exhibit 3, p. 24) shows some of the radioactive iron in the stem of the plant.

This shows two plants, one which had radioactive iron given to it in the seed by growing a plant in a solution where iron was available to it, and maturing seed that had radioactive iron in the seed. This plant had no iron in the seed, or no radioactive iron in the seed, but was put into a soil with radioactive iron. You see the radioactive iron made these first leaves quite green, and then it became chlorotic, and you can see that from the top leaves, the iron is about gone.

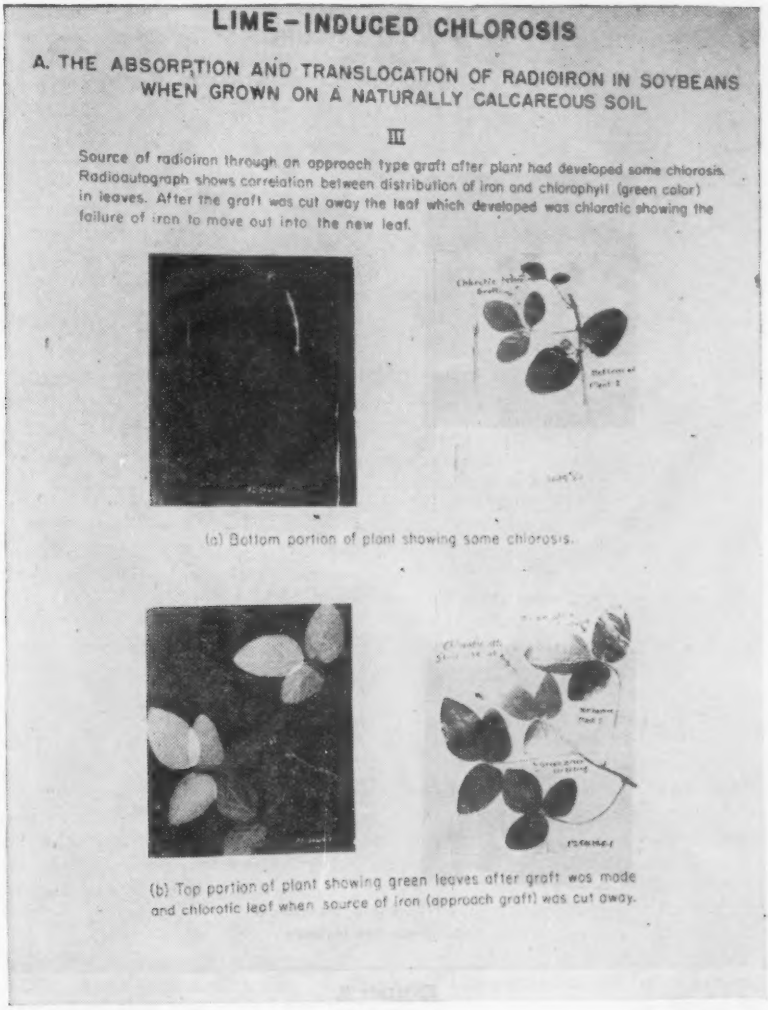
LIME-INDUCED CHLOROSIS
A. THE ABSORPTION AND TRANSLOCATION OF RADIOIRON IN SOYBEANS WHEN GROWN ON A NATURALLY CALCAREOUS SOIL
III
Source of radioiron through an approach type graft after plant had developed some chlorosis. Radioautograph shows correlation between distribution of iron and chlorophyll (green color) in leaves. After the graft was cut away the leaf which developed was chloratic showing the failure of iron to move out into the new leaf.
(a) Bottom portion of plant showing some chlorosis.
(b) Top portion of plant showing green leaves after graft was made and chlorotic leaf when source of iron (approach graft) was cut away.

EXHIBIT 2.

It merely used the iron that was in the seed, and then it was out, and there was nothing you could do about it.

This you will note is chlorotic all the way through and it was put in the same position on this film but it apparently took no radioactive iron from the soil.

Then one other interesting thing in fundamental research. Here we have a soil that is deficient in copper (see exhibit 4, p. 25). When they put radioactive iron in that soil, you will note that there is an excessive accumulation of iron in the nodes of the corn plant, these very bright spots here and then where the new nodes are coming out.

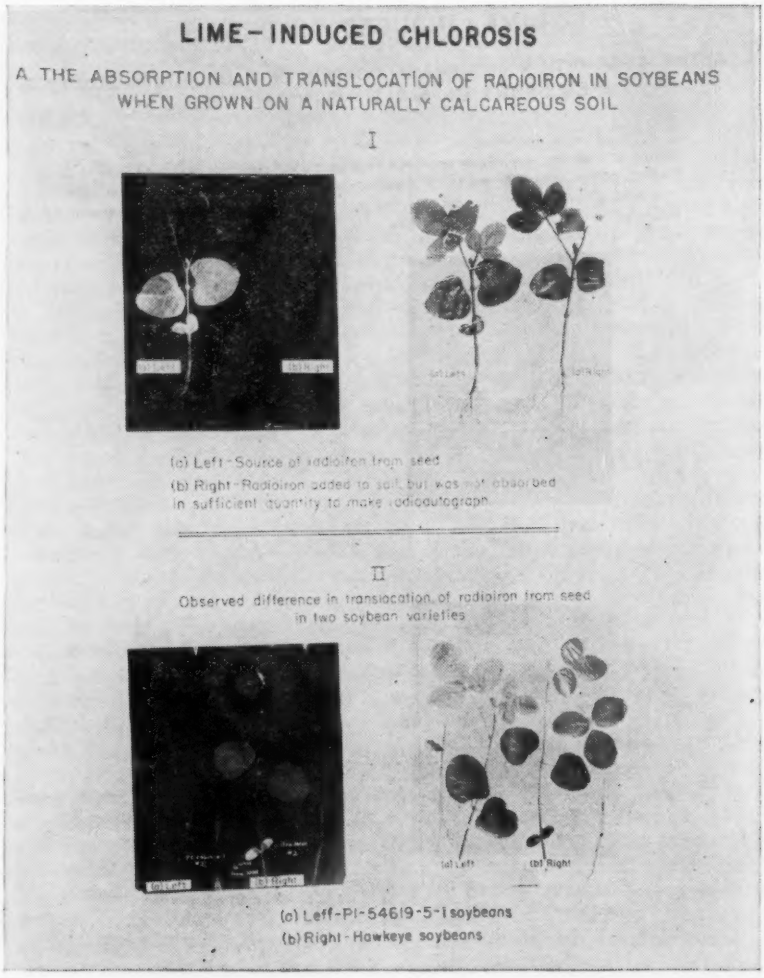
LIME-INDUCED CHLOROSIS
A. THE ABSORPTION AND TRANSLOCATION OF RADIOIRON IN SOYBEANS WHEN GROWN ON A NATURALLY CALCAREOUS SOIL
I
(a) Left - Source of radioiron from seed
(b) Right - Radioiron added to soil, but was not absorbed in sufficient quantity to make radioautograph
II
Observed difference in translocation of radioiron from seed in two soybean varieties
(a) Left
(b) Right
(a) Left - PI-54619-5-1 soybeans
(b) Right - Hawkeye soybeans

EXHIBIT 3.

You see an abnormal accumulation of iron under conditions of deficiency of copper. Down here is the same thing where copper sulfate was added, and you can perhaps see light spots but not the excessive accumulation of iron and abnormal growth that you had under the other conditions.

Thank you very much.

Representative HINSHAW. That is a very interesting presentation, Dr. Alexander. We are delighted to have you present here.

Senator BRICKER. The giving off of these rays in the isotopes did not in any way affect the plant growth or the substance of the plant itself, is that right?

Dr. ALEXANDER. You mean that the rays cannot make the plant grow?

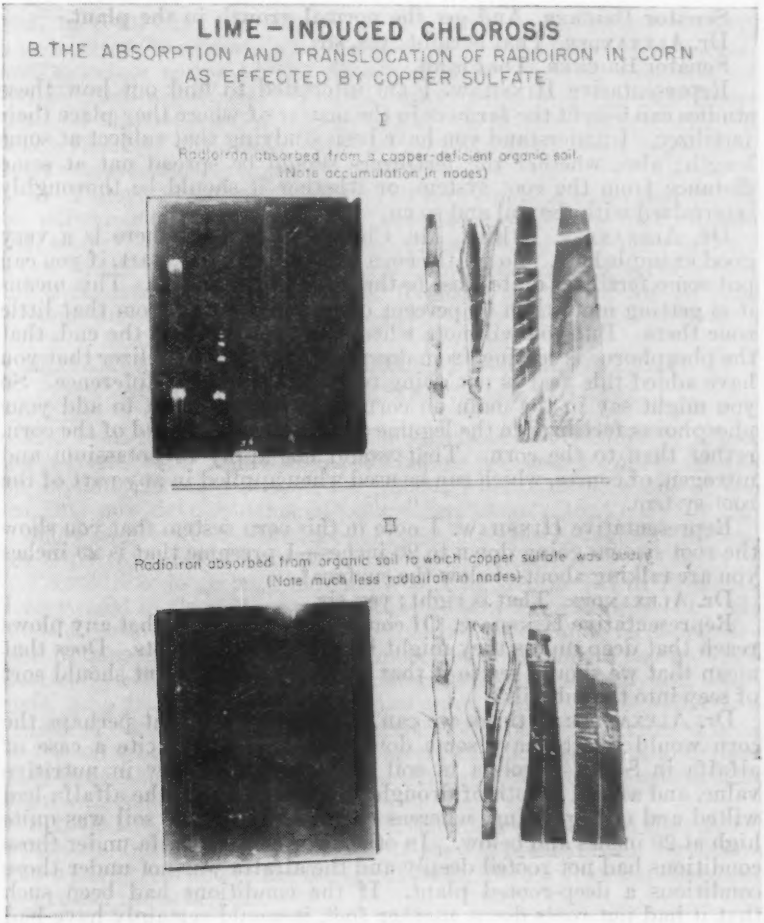
LIME-INDUCED CHLOROSIS
B. THE ABSORPTION AND TRANSLOCATION OF RADIOIRON IN CORN AS EFFECTED BY COPPER SULFATE
I
Radioiron absorbed from a copper-deficient organic soil.
(Note accumulation in nodes)
II
Radioiron absorbed from organic soil to which copper sulfate was added.
(Note much less radioiron in nodes)

EXHIBIT 4.

Senator BRICKER. Yes.

Dr. ALEXANDER. No, sir. I think all the evidence we have is that any effect that the rays have directly on the plant material would be deleterious rather than beneficial. There were considerable studies a few years ago, and there was some talk that it might be beneficial. There was rather extensive experiments run, and I think it was rather clearly shown that we could not hope to get any benefit by direct application of radioactive materials on farm land.

Senator BRICKER. What I was getting at is how much it harmed the plant and affected the growth of the plant.

Dr. ALEXANDER. In the concentrations that were used here, the effect would be either none or very small. That is one of the things that has been pretty thoroughly worked out with phosphorus, that is, the levels to which you can go without causing injury to the plant. That is one of the things a research worker must ascertain, what levels he can work at without causing injury to his plants.

Senator BRICKER. And get the normal growth in the plant.

Dr. ALEXANDER. That is right; yes, sir.

Senator BRICKER. That is all.

Representative HINSHAW. I am interested to find out how these studies can benefit the farmers in the matter of where they place their fertilizer. I understand you have been studying that subject at some length; also, whether the fertilizers should be spread out at some distance from the root system, or whether it should be thoroughly intermixed with the soil and so on.

Dr. ALEXANDER. I think, Mr. Chairman, on corn there is a very good example here. To get the corn off to a nice early start, if you can put some fertilizer quite close to the seed, it will help it. This means it is getting more than 60 percent of its phosphorus from that little zone there. But you will note when you come down to the end, that the phosphorus is coming from down in here. The fertilizer that you have added this year is not going to make very much difference. So you might say in the main on corn perhaps you ought to add your phosphorus fertilizer to the legume crop that comes ahead of the corn, rather than to the corn. That would not apply to potassium and nitrogen, of course, which can be used when applied in any part of the root system.

Representative HINSHAW. I note in this corn system that you show the root system going down to 20 inches—I presume that is 20 inches you are talking about—below the surface?

Dr. ALEXANDER. That is right; yes, sir.

Representative HINSHAW. Of course, I don't believe that any plows reach that deep unless they might be special instruments. Does that mean that we should see to it that the fertilizer nutrient should sort of seep into the subsoils?

Dr. ALEXANDER. I think we can put it this way, that perhaps the corn would like to have some down there. I might cite a case of alfalfa in South Carolina in soil that was rather low in nutritive value, and after 1 month of drought it was noted that the alfalfa had wilted and quit growing, whereas the moisture in the soil was quite high at 20 inches and below. In other words, the alfalfa under those conditions had not rooted deeply and the alfalfa was not under those conditions a deep-rooted plant. If the conditions had been such that it had put roots down another foot, it would certainly have had enough moisture to carry it through that month's dry spell.

Out in the West the alfalfa goes 6, 10, even sometimes 20 inches for moisture, but it is under conditions in which the fertility status—and probably calcium is one of the key elements there—is fairly high.

Representative HINSHAW. Thank you very much indeed, Dr. Alexander. We are delighted to have you come to visit us and to talk these things over. At some future time we hope to visit you when you are at work.

Dr. ALEXANDER. Thank you. We would be very happy to see you.

Representative HINSHAW. Now we have Dr. H. B. Tukey, who will discuss the foliar application of plant nutrients and radioisotopes in horticultural research. Dr. Tukey is head of the department of horticulture at Michigan State College. He received his bachelor degree at the University of Illinois, his doctor of philosophy at the University of Chicago. He has been the professor of pomology—which I presume has something to do with fruit—at Cornell University from

1927 to 1945. He is a member of the Royal Horticultural Society, a member of the editorial and executive staff of the Rural New Yorker, and associate editor of the American Fruit Grower, president of the Horticultural Society in 1947, was a delegate to the 13th International Horticultural Congress in London in 1952, has contributed much research and many publications on plant-growth regulators, fruit culture, and developmental morphology.

Dr. Tukey, we are very delighted to have you here today and expect to gain much from what you have to say. It is unfortunate that some of our Members have found it necessary to go back to their work on the floor of the House and Senate, but we are certain that the contribution you make will be found in the record for all time to come, and we greatly appreciate it.

STATEMENT OF DR. H. B. TUKEY, HEAD, DEPARTMENT OF HORTICULTURE, MICHIGAN STATE COLLEGE

Dr. TUKEY. Mr. Chairman and members of the committee, I, too, am honored to be asked to appear before you and I appreciate the opportunity to tell you something about what I think is one of the exciting new developments in agriculture, namely, that not only can plants absorb nutrients through the roots, but also through the foliage, the fruit, the twigs, the trunk, and even the flowers.

I would like to go back in history to King George III of England. Every child in elementary school knows about King George III. He made an award to his gardener, William Forsythe, upon recommendation of a commission from Parliament for revealing to the public a particular concoction of certain materials from the barnyard, soapsuds, lime from an old building, and so on, which put together and plastered onto trees, and then covered with a powder of burned bone and wood ashes, encouraged the recovery of wounded trees, and quite influenced the growth of the trees. All of this was viewed at that time with some misgivings.

A little later in California in 1914, scientists working on the control of insects and diseases found that if they applied certain fertilizers to dormant trees and to the foliage of trees, there was an improvement in growth the next year.

Again in Oregon a few years later, some outstanding work in spraying dormant trees with fertilizers improved the growth of trees.

Senator BRICKER. In spring and during the wintertime?

Dr. TUKEY. Yes, sir. In fact, after a severe winter in Michigan a few years ago, we also tried spraying dormant trees with fertilizers. Winter injury frequently appears in isolated areas of the tree the next year, in which the new leaves show symptoms of a deficiency of certain nutrients, as potassium. Our thinking was that if these areas could be maintained alive just as one might drop supplies to mountain climbers to keep them alive until communication can be established, perhaps the tree would regenerate more easily and recover. We feel that the treatments were helpful, but here again the result was looked at somewhat askance and with some doubt.

This is where radioisotopes have been a great help and have clarified the situation. We received from the Atomic Energy Commission radio phosphorus and radio potash. These in the wintertime were made into solutions, cotton gauze was dipped into them and wrapped

around the branches of the tree, and then tested for radio activity by means of a counter such as you see in the case. Within 24 to 48 hours, even in midwinter and at below freezing temperatures, we could find these materials in verticle branches 18 inches to 2 feet above the point of application. Further they tended to accumulate near the bud, and so, from these tests, the question of entry of nutrients into dormant branches has been established, and the practice that growers have adopted in California of spraying fruit trees in the dormant season with zinc is rationalized

It might be mentioned in passing that the surface area of the twigs, branches, and trunk of a 25-year-old apple tree—we cut one down and measured it—is 800 square feet, which of course would be equivalent to a surface 100 feet long and 8 feet high. Furthermore, we were able to spray on this area the equivalent of 3 pounds of fertilizer. You, see therefore, that the idea does have some basis in fact.

While all of this is interesting, I think the most exciting news is in the foilage feeding of plants—that plants can take up nutrients through the foliage. Here is a case where the farmer has really gotten ahead of the scientist as so often happens. He has learned that foliage feeding is helpful and he has adopted the practice. This has come about by virtue of the fact that a number of favorable factors have concentrated all at once to make this possible.

For example, as you well know, spraying is a common procedure on the farm these days. Fungicides, insectitcides, and herbicides, and fly and livestock spraying techniques are everyday occurrences. People understand the spraying technique.

Second, we have machinery that is marvelously efficient. We can apply materials in great quantities very rapidly and with great exactness. Here is a picture of such an application being made to fruit trees in the field. (See exhibit 5, p. 29.) Dr. Wittmer, who is changing the charts for us is one of our research team. Research these days is done by teams and not by individuals. He is one of the very important members of our team.

Senator BRICKER. Is that a fertilizer, insecticide, or a combination?

Dr. TUKEY. This is a combination of fertilizer with insecticide. This is a common way of applying them. And here is a picture of application to vegetable crops. See exhibit 6, p. 30.)

Furthermore, we now have new materials available which are ideally suited to spray applications that we apply these days. Instead of limestone, bonemeal, raw rock phosphate, and that sort of thing, we now have fertilizers which are completely soluble in water, such as urea, which carriers up to 40 percent of nitrogen, othophophoric acid, and so on.

Also horticulturists perhaps more so than some other groups, because of the nature of their crops, find critical times in the development of a plant when nutrients should be applied. At other times they should be withheld. A cherry fruit, for example, does not just swell up as it grows. The cherry grows for a certain period of time and then stops for several weeks. In the period of time when the cherry is apparently not growing, the pit is hardening. Inside the pit the embryo is growing at still a different time. And so at one time one part needs magnesium, another needs phosphorus, and so on. We are developing a more critical evaluation and control of crops.

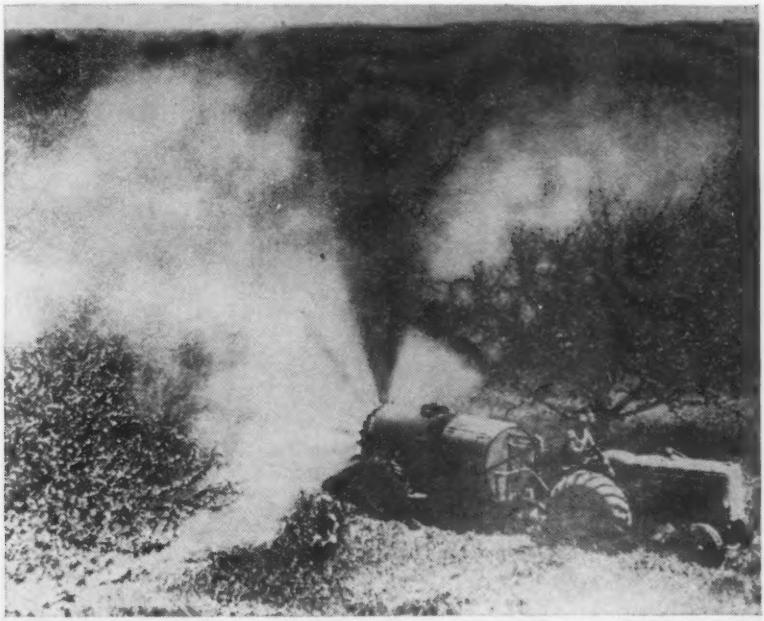

EXHIBIT 5.—Recent advances in engineering and in soluble fertilizers now make foliar applications practical (apples).

Through all of this, the isotope technique is very effective. In this technique, of course, we take such a plant as Dr. Hendricks showed you over there, which we have treated with a radioactive material. After a period of time the plant takes up the material. The plant is destroyed and dried, a piece of X-ray film is placed against it, and the two are put into a dark box for a matter of days. The result is these beautiful radioautograms that I show here, and showing the distribution of these materials in the plant. Or we use a Geiger counter or some other measuring device.

This picture illustrates the movement of some of these materials. (See exhibit 7, p. 31.) The first point I should like to make is that the materials do enter the leaves rather easily. Here is a tomato plant, and you can see that the materials have entered the plant and have moved outward from the leaf in all directions. Here is a corn plant. We have worked with a number of plants, showing that the phenomenon is not restricted to just these few crops.

In final analysis we find that a leaf is a very efficient organ of absorption. We find that the materials move into the upper surface of the leaf as well as the lower surface. We find that it enters at night and during the daytime. Further, we find the leaf surface of a 12-year-old apple tree in Washington State to be equivalent to one-tenth of an acre, even though that tree only occupies about one-hundredth of an acre. So three is a large feeding areas.

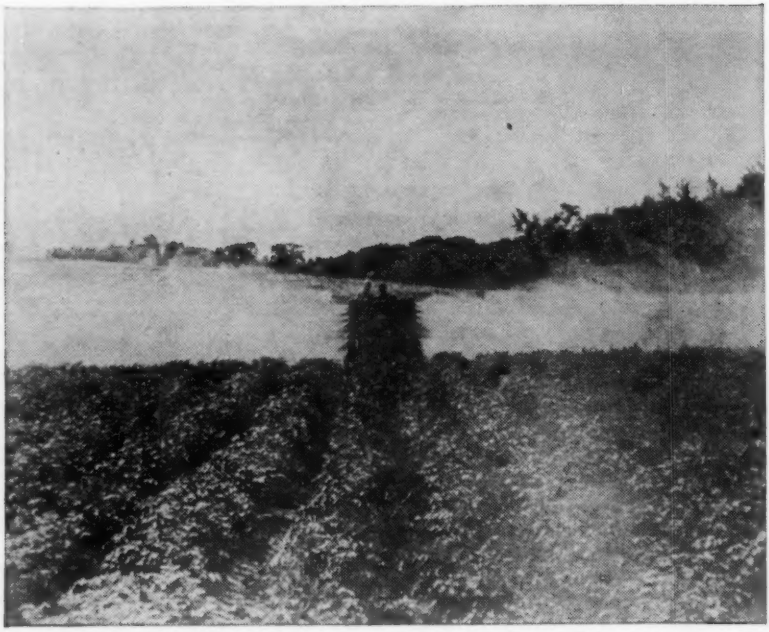

EXHIBIT 6.—Recent advances in engineering and in soluble fertilizers now make foliar applications practical (potatoes).

Representative HINSHAW. Is that when the leaves are fully out?

Dr. TUKEY. Yes, sir; that is when the leaves are fully out.

Representative HINSHAW. It has 10 times the area that the tree actually covers in the area of absorption.

Dr. TUKEY. Exactly. So it really is a substantial area for coverage. Not only do these materials enter rather easily—and this is interesting, too, because all the textbooks used to tell how the plant was covered by an impervious cuticle—now we find the textbooks are rewritten and the leaf is reported as a beautiful mechanism for absorption—if we apply some of this material to the leaf of a bean plant, the material moves very quickly into all parts of the plant. You notice in this photograph how it concentrates in the growing tips of the roots even way down in the soil. Commonly it accumulates in the most actively growing regions. This is of some importance, too, to plant breeders, and I am sure that you will hear about this from Dr. Singleton tomorrow in terms of plant breeding. Some of the research workers in Sweden and some in this country as well are now utilizing this technique, whereby using a higher concentration of phosphorus than has been used commonly in fertilizer treatments, the radioactive material accumulates in the buds and other susceptible parts where it may induce genetic change, and produce a new form of plant—a mutation.

If we compare leaf feeding with soil feeding, as in these photographs (see exhibits 8 and 9, pp. 32 and 33), this is the root application and this is the leaf application—if we apply it to the root, we

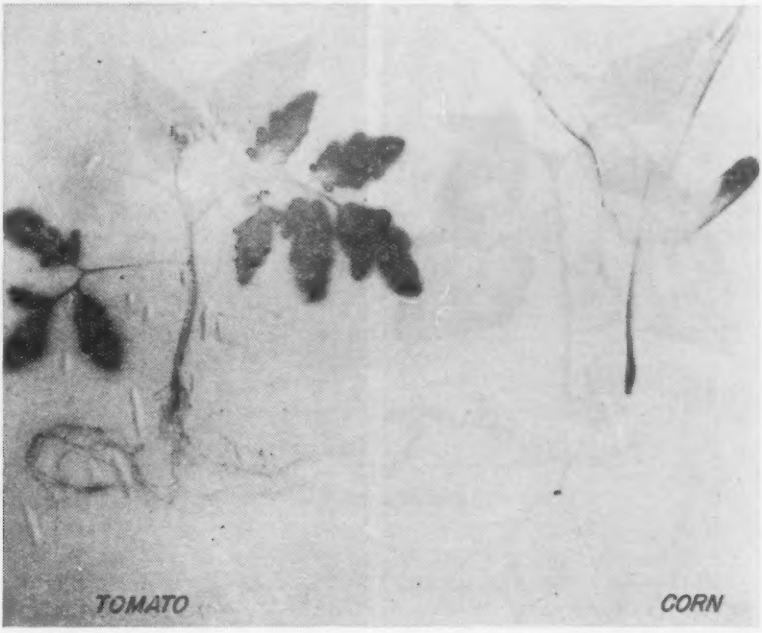

EXHIBIT 7.—Absorption and movement of I^{32} following foliar applications.

see it moves upward in the plant. If we apply it to the leaf, we find it moves downward through the plant—at the rate of a foot an hour. It is very interesting that it moves so freely. If we apply it to a middle leaf, it moves both ways very effectively.

I mentioned the fact that there are certain parts of the plants that need certain nutrients at certain times. We find, for example, that when a seed is forming in the strawberry the phosphorus concentrates immediately in the seed. (See exhibit 10, p. 34.) We find in the case of the apple that both phosphorus and magnesium concentrate in the seed when it is developing. This is a very interesting point to fruit growers, because they have noticed the magnesium deficiency appears in the foliage in the summer. This is when the seed is drawing magnesium from the leaves, when the supply is short, and so magnesium deficiency shows up in the foliage.

We have seen that materials are absorbed by the plant and move rather freely in the plant. The amounts may at first seem relatively small, but to offset this handicap, the efficiency is high. In fact, this is the most efficient method of applying fertilizer to plants that we have yet discovered. If we apply these materials to the leaves in soluble forms, as much as 95 percent of what is applied may be used by the plant. If we apply a similar amount to the soil, we find about 10 percent of it to be used.

This chart helps to clarify this matter of efficiency. (See exhibit 11, p. 35.) We apply the material here to the leaves—and of course the fruit is quite near the leaves, which may be a point. Now if we

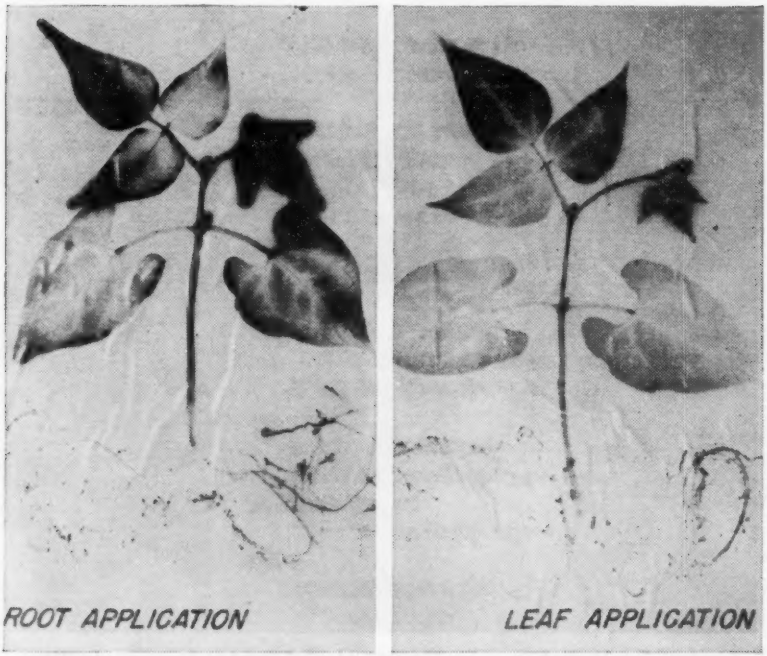

EXHIBIT 8.—Absorption and movement of P^{32} in bean plants.

follow this curve of the total phosphorus in the fruit derived from foliar application, we find a substantial amount at 14, 15, 16, perhaps 30 to 40 hours after application. Contrast this with the soil application where the rate is much slower. This is very important in certain critical times of the year.

For example, the soil may be cool and low in phosphorus at just the time it is needed by a transparent vegetable or strawberry plant. Or there are cases where the soil locks up certain materials that are applied, like potash and magnesium. Under such conditions we find leaf application very significant and very effective.

Now let us take a look at calcium. Calcium behaves quite differently. If we apply calcium to the foliage of the plant, it moves into the plant, to be sure, but it does not move down to the roots with any great degree of freedom. Applied to the soil it moves upward through the entire plant. Applied to the leaves, it does not appear in the roots. This is of considerable importance to us when it comes to growing strawberries. Here is a radioantogram of a mother plant that was treated with radiocalcium. (See exhibit 12, p. 36.) You will notice how the material has moved through the plant and moved over here to adjacent plants and into the foliage of that plant. But you will also notice that it has not moved into the roots of the daughter plants. In other words, the daughter plants might starve to death for lack of calcium if the material is available only through the leaves.

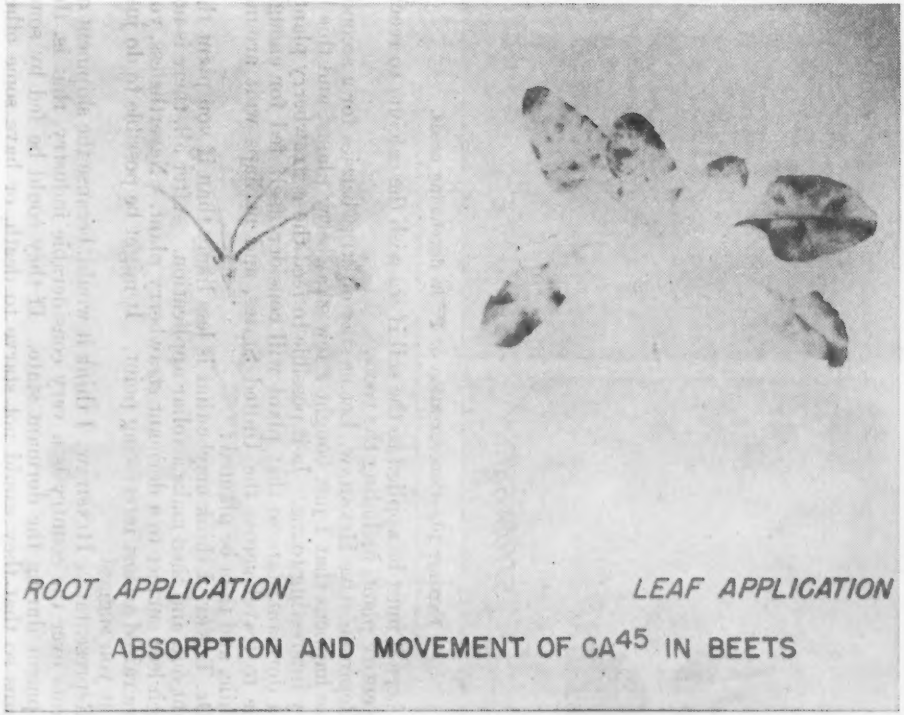
ROOT APPLICATION
LEAF APPLICATION
ABSORPTION AND MOVEMENT OF CA45 IN BEETS

EXHIBIT 9.

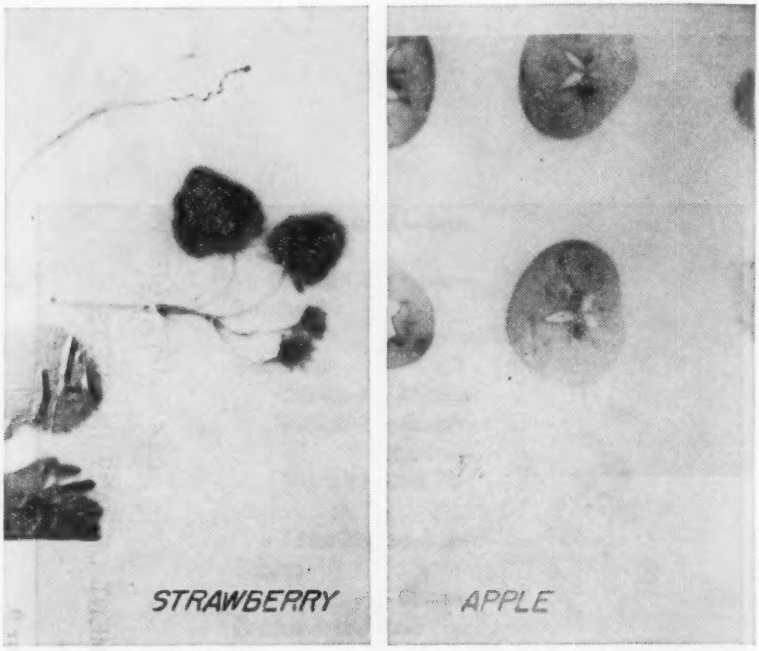

EXHIBIT 10.—Concentration of P^{32} in developing seeds.

So here it must be applied to the soil if we wish the calcium to reach the entire plant, including the roots.

Representative HINSHAW. Let us stay on strawberries for a second. It so happens that I just bought a few strawberry plants, and this is very interesting to me. Is it possible to feed those strawberry plants in a dormant state so that plant will consider itself fed for enough time to travel across the United States, and perhaps wait around awhile, and then be planted?

Dr. TUKEY. I think maybe that is less likely than if you plant the plant out, and then make a foliar application. After all, there is not much leaf surface to a dormant strawberry plant. Nevertheless, you have raised a most interesting point. It might be possible to do just what you suggest.

Representative HINSHAW. I think it would, because the shipment of plants over the country is a very considerable industry, that is, the shipment during the dormant state. If they could be fed by some means so that they would not starve to death, or have some other casualty befall them—you cannot stop them from drying out—you could feed them and they would not have to have very much root surface to feed from if they were fed from the other parts of the plant.

Dr. TUKEY. That is a very worthwhile thing to follow up. This might also be carried through to some other perennial plants and to nursery stock in general.

Representative HINSHAW. Yes.

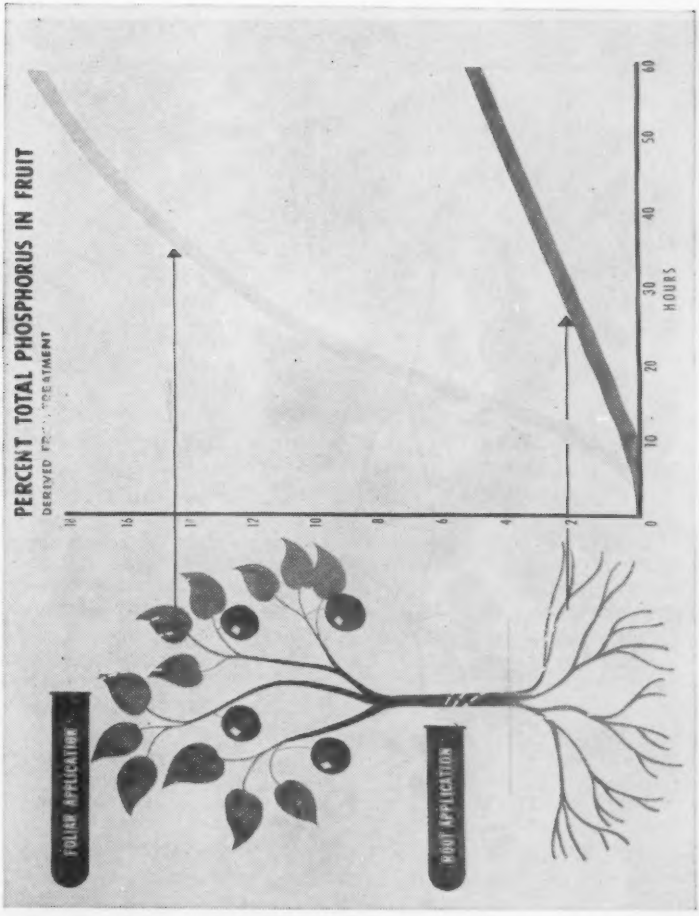
PERCENT TOTAL PHOSPHORUS IN FRUIT
FOLIAR APPLICATION
ROOT APPLICATION
HOURS
0
10
20
30
40
50
60
2
4
6
8
10
12
15
16

EXHIBIT 11.

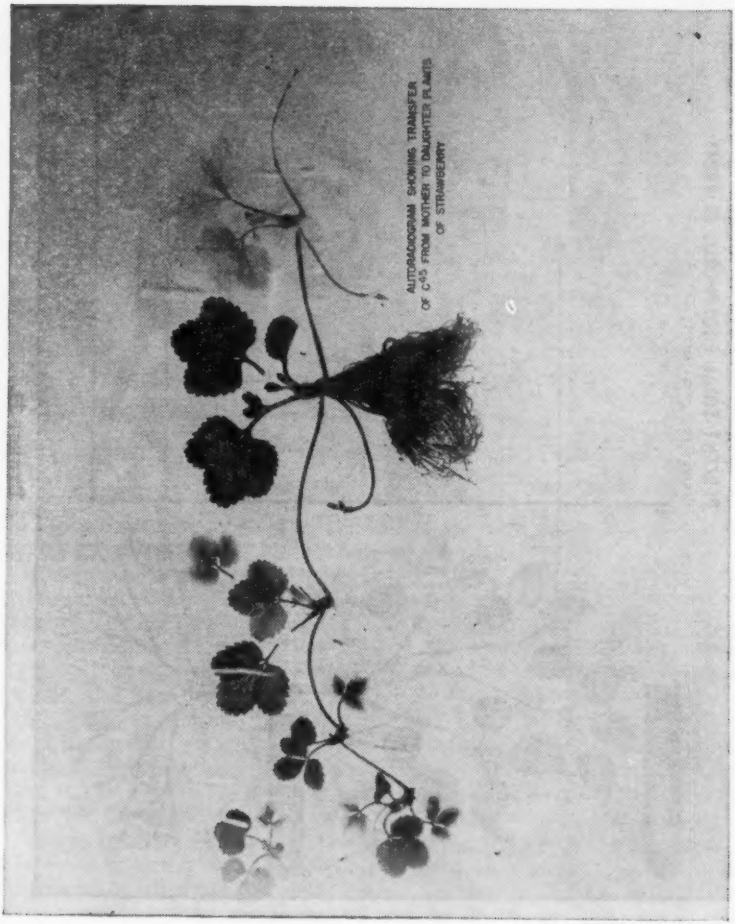

EXHIBIT 12.—Autoradiogram showing transfer of C^{45} from mother to daughter plants of strawberry (note absence of C^{45} in roots of daughter plants).

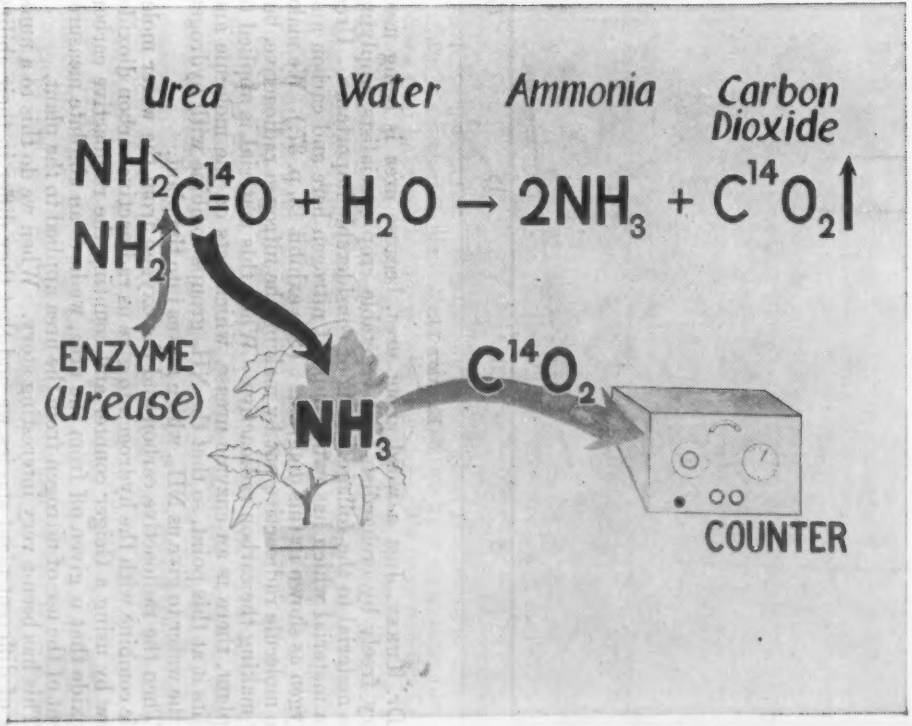

EXHIBIT 13.—Method used to trace urea in foliar application.

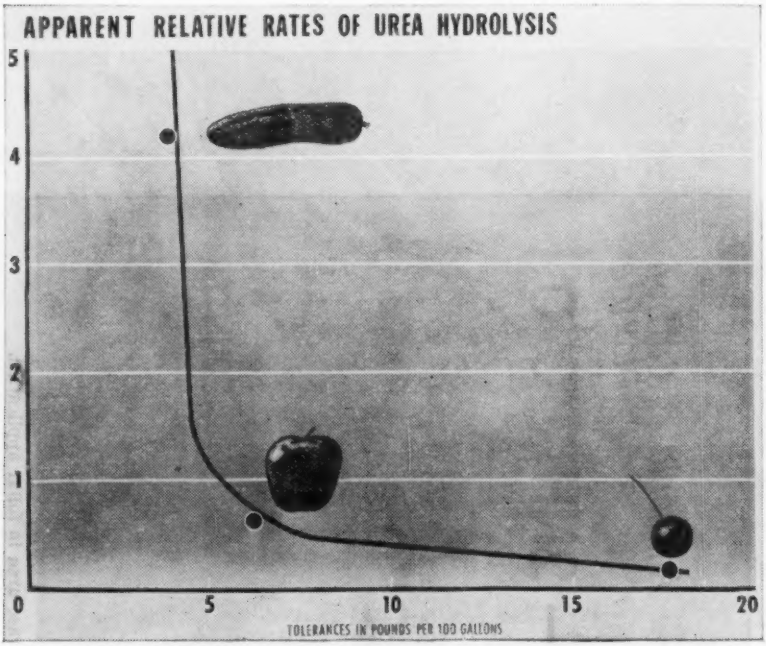

EXHIBIT 14.

Dr. TUKEY. Just a word about urea, because urea is being used very freely by orchardists and vegetable crop specialists, applying the material to the foliage. It is of considerable importance. Urea is a material which has two groups of nitrogen here and carbon and oxygen as shown in this diagram. (See exhibit 13, p. 37.) We make the molecule radioactive not by making the nitrogen radioactive, but by making the carbon radioactive. When this material is applied to a plant, there is an enzyme urease, which acts on the molecule and splits it at this point, so that the NH_2 groups combine with hydrogen in the water to give us NH_3, which moves into the plant.

Then the radioactive carbon and the oxygen from the water molecule combine with the hydrogen to give us radioactive carbon dioxide. Now by using a Geiger counter and counting the radioactive carbon dioxide that is given off from the urea, we have an absolute measurement of the use of nitrogen from the urea applied to the plant.

This has been a very interesting story. When we do this to a number of different plant species we find that they differ in their ability to utilize urea. Here again is the sort of thing the farmer has found out to some degree. In the case of the cucumber, for example (see exhibit 14, above) we find that it can use urea very rapidly. In fact, in a matter of a few hours the small amount which we put on a cucumber leaf in our tests is entirely used up.

By contrast, a peach and a cherry and a potato plant utilize material very slowly. You see in this chart that the amount used is way down

here, below "1" on the scales compared to above "4" for the cucumber plant. In between is the apple. Between the apple and the cucumber are the tomato and corn. Low in the scale is the peach, which does not respond very well, and the plum which also does not respond very well. And so we can take into the laboratory certain plants, measure them by this technique, and secure an index of response that might be expected from urea application using this radioactive technique.

This is not all. We find that certain plants will tolerate higher concentrations of urea than others. We find that the cucumber, which utilizes urea so rapidly, will tolerate only a concentration of 3 to 4 pounds per hundred gallons. On the other hand, the crops that utilize it the least will tolerate the most, some up to 20 pounds of urea per hundred gallons. This rationalizes and makes sense out of a number of experiences that have been confusing in various parts of the country. We feel that this technique is a significant help.

The whole field, as I have said, is a field of considerable interest and considerable promise. The thing that impresses, I think, is not how much we know but how really little we know. You will recognize that this afternoon I have talked about phosphorus and calcium—I did not mention potash, though I might have. I could also have mentioned strontium, which follows somewhat the pattern of calcium. I could mention magnesium and how in celery deficiency is cured rapidly by epsom salts (magnesium sulfate), making a whole crop that was formerly thought unmarketable, marketable. But, though we know of a few things, we are impressed, as I have said, with how little we know. Because, we have a great number of elements that must be taken into consideration. Also, we have numerous formulations that have not been critically studied. We have not touched insecticides and fungicides and herbicides. It is entirely likely, and it seems possible, fruit growers have noticed it, that when we use certain fungicides on a plant, the plant grows better. It is strongly suggestive of the fact that some of these materials are used as nutrients by the plants, and I could name some of them.

Still further, since materials move into the leaf, we are highly suspicious that they move out of the leaf as well. We would like to carry on a project in which we leach materials from the leaf. In some locations where certain fruits do not set well, we make the explanation on the basis of adverse temperatures and perhaps sunlight. But now we are highly suspicious that here may be a case where materials are actually being leached out of the leaves, maybe by overhead irrigation, maybe by rain, and having a profound effect upon the crop. Here is a whole additional new field that needs exploration.

To summarize, I have shown that the value of leaf feeding is established. Entry is certain. Movement occurs within the plant. We have materials that are available, suitable and effective. We have apparatus that is well suited to our needs. The limiting factor is knowledge and this is where the radioactive isotope technique promises a great deal for the future.

Finally, Mr. Chairman, may I comment, and I will end as I began, that King George III of England, regardless of how we may feel about his judgment on other matters, is vindicated in the matter of giving a reward to his gardener, William Forsythe, for plastering

fruit trees with peculiar barnyard concoctions that were said to improve the growth of the trees.

Thank you very much.

Representative HINSHAW. Doctor, you have explained a couple of techniques that I will not describe that were engaged in by my grandfather. I will not describe them here, because they are not particularly beautiful. But on the other hand, they were very effective. I always wondered why. Now I see that my grandfather should have received a medal along with Mr. Forsythe.

Dr. TUKEY. There apparently was always some relation between evil smells, weirdness, and black magic, and the efficacy of the compound.

Representative HINSHAW. He made a poultice out of familiar elements and applied them to some trees that were injured, and it seemed to be very satisfactory.

I am particularly interested in this. It is a very interesting subject. I presume that you have discovered by what process the leaf of the plant takes in this material—whether it is just straight through the pores of the plant in an absorption way, or whether it combines with some element in the leaf at once, that is, the leaf element on the exterior of the leaf or some other method. How do you figure that?

Dr. TUKEY. I am sorry to say that there is much left to be desired in our knowledge on this topic. But I can add this: Whereas at one time we felt the leaf was covered with a cuticle impervious to water, now we find that certain tissues come right to the leaf surface, making a connecting link right from the leaf surface, so that when the material touches there it is absorbed and moves through the cell walls and into the leaf.

Representative HINSHAW. Does it move fast?

Dr. TUKEY. It moves surprisingly fast. We used to think that the materials must move through the openings on the underside of the leaf, and sometimes on the upper side. This is no longer true. It is now thoroughly established that there are regions on the leaf where materials may enter and are actually almost like a blotter, drawing them right down into the leaf.

Representative HINSHAW. That must have some dark and deep history back in early times, that is, a million years ago or so, when it was found to be an efficacious means of receiving food into the plant. Otherwise, the plant would not do that; is that correct?

Dr. TUKEY. That would seem proper. Gardeners years ago have maintained some of these things, but they were denied by many.

Representative HINSHAW. We generally find that these processes that take place unbeknownst to us have some foundation in primordial times. For example, somebody probably some day will find a good reason why man has tonsils. We must have used them at one time in history. So perhaps we can say in earlier days we might have had mudstorms or we might have had some other things that would account for this absorption principle, or else that plant life, having started in water—that is, submerged completely, it must have been submerged at some time—that perhaps it learned how to absorb food at that stage in early history, I do not know, 10 million years ago or so, or a hundred million years ago, or a billion years ago.

Dr. TUKEY. At least we now know we have a mechanism in the leaf for absorption that we did not realize we had a number of years ago. That makes a lot of things rational, as you say, that we doubted before.

Representative HINSHAW. I take it that these water weeds that grow wholly submerged in water must absorb practically all of their food through the leaf and stem, is that not true?

Dr. TUKEY. It would depend on the supply of nutrients in the water. It could be that they could do this. If you think in terms of a lake or stream where the water has a very small amount of nutrient, I would be inclined to doubt whether they would derive enough from the water. Perhaps if we could increase the amount, then I think this could be done. I know, for example, that with tomato plants you can cut off the roots and take the leaves and put them in beakers of sugar and other nutrients and you can grow them very nicely without any roots. For that matter, certain of the giant algae that grow in seawater attach themselves to a rock, and evidently absorb needed nutrients directly from the water.

Representative HINSHAW. It has been a very interesting discussion. I am sorry that all of the members of the committee could not have been here to hear it. We thank you very much indeed for coming this far from the great State of Michigan, although I understand that in the course of it you doubtless escaped a little weather.

Dr. TUKEY. We did. Thank you very much.

Representative HINSHAW. Thank you, sir.

We note with pleasure the attendance here with us today of Dr. Smythe of the Atomic Energy Commission. We are delighted to have you present, Doctor.

The meeting will stand adjourned until tomorrow at 2 o'clock when we will hear a very distinguished list of persons, Dr. Singleton, Dr. Stakman, Dr. J. C. Shaw, and Dr. Butts. With that hearing we will conclude for the time being and hope to visit you all in your home laboratories at the first opportunity.

(Thereupon at 4:10 p. m., Wednesday, March 31, 1954, a recess was taken until Thursday, April 1, 1954, at 2 p. m.)

THE CONTRIBUTION OF ATOMIC ENERGY TO AGRICULTURE

THURSDAY, APRIL 1, 1954

CONGRESS OF THE UNITED STATES,
RESEARCH AND DEVELOPMENT SUBCOMMITTEE
OF THE JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D. C.

The subcommittee met at 2 p. m., pursuant to recess, in the caucus room of the House Office Building, Hon. Carl Hinshaw (chairman of the subcommittee) presiding.

Present: Representatives Hinshaw (presiding), and Jenkins.

Representative HINSHAW. The committee will come to order. Today, we have as our first witness, Dr. Ralph Singleton, senior geneticist of the Brookhaven Laboratory of Long Island, N. Y. He received his degree as bachelor of science from Washington State College, and his doctorate of philosophy from Harvard University. He is a geneticist who was with the Connecticut Agricultural Experimental Station from 1927 until 1948. During that time, he served with the United States Department of Agriculture, the International Congress of Genetics in Edinburgh, and the University of Minnesota, I presume on the faculty, in 1941. He has been a delegate to the Ninth International Congress of Genetics in Italy in 1953. He has conducted outstanding research and is responsible for many publications in the field of genetics of corn and cereal crops.

Dr. Singleton, we are delighted to have you present.

STATEMENT OF DR. W. RALPH SINGLETON, SENIOR GENETICIST, BROOKHAVEN NATIONAL LABORATORY, LONG ISLAND, N. Y.

Dr. SINGLETON. Mr. Chairman and committee members, I am happy to be invited here to testify to the relation of genetics to agriculture. I might preface my remarks by saying that I firmly believe that the science of radiation genetics will soon become one of the most important events in the history of agriculture and may far outshine such historic events as the development of hybrid corn.

I say this having had 21 years' experience at the Connecticut Experiment Station working with hybrid corn and with Dr. Jones who is more or less the founder of hybrid corn.

In the few minutes allotted to me, I should like to tell you about the events which have led me to take such an optimistic point of view. Although it has been known for more than a quarter of a century that radiations such as X-rays cause mutations, that is, changes which will be subsequently inherited from generation to generation, it was believed that all of the changes produced in this way would necessarily be deleterious to the plant or animal.

With the advent of atomic energy, which made sources of radiation more readily available, it was felt desirable to reinvestigate this problem not only because there were very much more potent sources of radiation at our disposal, but also because we now had different kinds of radiation for experimental use.

The most noteworthy of these new radiations is the neutron which seems to be a selective tool in that it is absorbed largely by nitrogen atoms in the nucleoproteins of the chromosomes. Thus, the radiation is delivered to the hereditary carriers themselves, the chromosomes.

The radiation genetics problem was approached from two different points of view. The first was a program designed to give us a better understanding of the science of radiation genetics and consequently of genetics itself.

Representative HINSHAW. You call that the science of radiation genetics?

Dr. SINGLETON. Yes; and that is by using radiation, we are studying genetics. We are studying gene changes, trying to find out what makes a gene change. This ear of corn, for example, that you see here—and I might pass it to you for your examination—has some mutated kernels on it. You can see that it is all red except for 3 or 4 kernels. That was grown in our radiation field, and the radiation caused a change which involved those three kernels. We also have some involving only a single kernel, such as this ear of corn here.

The second was a much more practical approach to the use of radiations for the solution of specific agricultural problems. I am happy to report that these two approaches are augmenting each other remarkably well.

By means of our fundamental studies, we have been able to define accurately the way in which the radiations should be given, the biological conditions which must be fulfilled, the kind of radiations to use, the kind of results which may be expected, as well as a great many other factors which must be known before one can approach the problem intelligently.

These studies have further shown that the old concept that all radiation induced mutations are deleterious to the plant is not correct. We have evidence that some radiation-induced mutations are desirable changes. As a direct result of these fundamental studies, we have been led within the past couple of years to apply the results of these studies to the solution of specific agricultural problems. These studies are still in their infancy, but the results so far are even better than we had dared hope for.

I might say that I am happy that this hearing was held this year instead of last year because most of the accomplishments that I am reporting today could not have been reported a year ago, such as the rapid pace with which this science is developing.

One of the most spectacular of these results is the development of rust-resistant oats by means of neutron irradiation, as reported by Dr. Calvin Konzak, of the Brookhaven National Laboratory, last fall. He set out to create a variety of oats which would show a good yield and at the same time be resistant to a particular strain of oat rust. After only 1½ years and at a very small cost he has a small amount of oat seed tailored to these specifications. This is something which would have taken at least 10 years by conventional plant breeding methods, and at considerable expense.

I am sure it is well known to all of you that plant diseases of many kinds are with us continually and cause an estimated annual agricultural loss of $3 billion. New and unusually severe diseases sweep the country from time to time. I am not going into the plant-disease problem very extensively because we have one of the world's most eminent plant pathologists with us, Dr. Stakman, and he is going to tell you about some of these things in the next speech.

I believe you will agree with me that the development of any method which promises to produce quickly crops immune to these diseases is of major importance to the country.

We are right now setting up a program to produce strains of corn resistant to a leaf blight. We plan to make the radiations at Brookhaven this summer and we will grow the crop in Florida this coming winter, and next summer we will be able to test to see whether we have resistance.

Judging from our experience with oats, we believe we can develop resistance to this disease in a comparatively short time. I have a letter that just came in before I came down from my friend Glenn M. Smith, who originated golden cross bantam, and he says that this disease is severe in Florida and that they spray some 25,000 acres of sweet corn each year. I believe that we can produce a strain that is resistant to this disease.

Disease resistance is by no means the only desirable characteristic which can be induced by radiation. The most striking example so far of the induction of other characters is that of Dr. Gregory of the North Carolina State College of Agriculture. He set out to develop peanuts having a number of different agriculturally desirable characteristics by the use of radiation.

So far, he has produced a variety of peanuts which has about a 30-percent higher yield per acre; another type having a size and shape better adapted to mechanical harvesting as well as a variety resistant to common leaf-spot disease. I have some photographs here which I will show you. (See exhibit 15, p. 46.) The one on the left is the induced mutant that has all of its foliage, whereas the one on the right has been defoliated by the leaf-spot disease. This is a creation of radiation, and in this case he used X-rays. You can see in the projectograph in the back of the room we have a series of pictures from Dr. Gregory, and these show the work that he has done. (See exhibits 16 and 17, pp. 47 and 48.)

Representative HINSHAW. Let me ask you, Doctor, do you go at this problem intentionally, or is it an accidental mutation of the variety that is induced by radiation, and then a process to select that which does the best?

Dr. SINGLETON. That is right. We cannot predict exactly what percentage of what type of gene we will change. We know if we give a sufficient amount of radiation, we will produce mutations such as the one you had up there, and I think our maximum number of mutations is about 3 to 4 percent per gene. These are the characters that we have studied. They are the kernel characters of corn, largely, but these mutation laws are universal, and there is no reason to suppose that all of the genes of a corn plant or any other plant will not be subject to this same change that we produce in these genes that we can study.

EXHIBIT 15.—Right row shows disease-resistant plants produced by radiation. Susceptible normal plants on left completely defoliated by leaf-spot disease.

So, we treat these with X-rays or neutrons, or our gamma field which we will tell you about in a moment, and then we know that we are inducing a lot of variability. Then, as you say, it is a process of selection of the kinds that you want, and discarding the ones that you do not want.

I might add that most of the changes that are produced are deleterious, that is, harmful. But if only one in a thousand is beneficial and we screen enough material, we will catch that one. It is fairly easy to screen for things like disease resistance.

Does that answer your question, Mr. Chairman?

Representative HINSHAW. Temporarily; I have some more.

Dr. SINGLETON. Now, this is another result of Dr. Gregory's work (see exhibit 18, p. 49) and I told you about the yield of peanuts. This is a progeny that came from an X-ray-induced mutation or change, and here is a normal one on the right of the picture. In this case, of course, and this is the proof of the pudding, we have a peanut variety that yields better. Not only has Dr. Gregory done it but the Swedish workers have produced higher yielding strains of cereals several years ago by use of X-ray radiation.

I have, of course, chosen two of the most spectacular examples so far, but there are enough others to make us confident that the method

EXHIBIT 16.—Testing radiation-induced mutant peanuts in North Carolina studies selected progenies stakes.

is completely valid. This will give you some idea of the reasons for my optimism. Now I would like to summarize briefly the program we have underway.

We are, of course, continuing our program of fundamental research in radiation plant genetics. We are continually finding out not only a great deal more about the science of genetics, but about the way in which this science can contribute to agriculture.

On the practical side we are, of course, continuing with a greatly increased program of crop improvement by irradiation of seed. This is being done largely through the cooperation of the universities and agricultural experiment stations. Thirty-eight different institutions from Maine to California, also Alaska, have sent seed to Brookhaven National Laboratory and after consultation with the staff members the seed has been irradiated and sent back to the original institution for growth according to plan.

The results of these studies should be forthcoming in the next few years. Some of the more difficult of the practical problems are being tackled at the various State agricultural experiment stations, the USDA, and the national laboratories.

For example, methods have now been worked out for inducing mutations in corn efficiently and I am now planning a series of experiments extending over 2 years which will, at the same time, I hope, develop

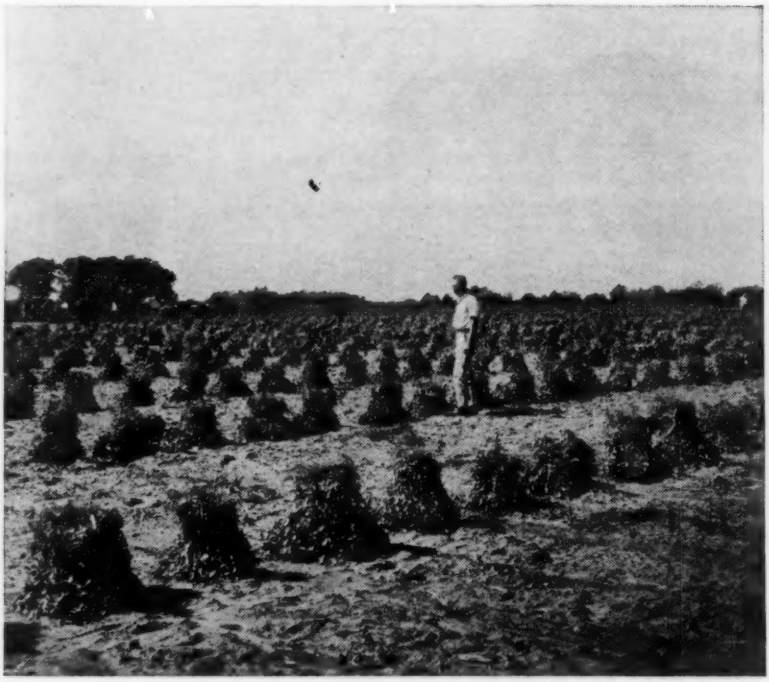

EXHIBIT 17.—Harvest time in North Carolina. Peanut radiation experiment. Each shock represents different progeny being tested.

inbred strains of corn suitable for producing hybrid corn which is resistant to *Helminthosporium turcicum* leaf blight and as a consequence higher yielding than present hybrids, with much greater efficiency than formerly.

I want to tell you a little bit about our gamma field and our radiation field. (See exhibit 19, p. 50.) The original one was set up in 1949. We set up a 3-acre field with a 16-curie source which we used for 2 years. In 1951 we had this larger source of about 145 curies and in 1952 it was 260. In 1953 we went up to 1,800 curies, which is a highly potent source of radiation.

Representative HINSHAW. Do I understand you correctly that you use Cobalt 60 as a radiation source?

Dr. SINGLETON. Yes; that is right.

Representative HINSHAW. And is it so powerful that you have to let it go down below the surface if you want to approach the field?

Dr. SINGLETON. That is very good. You have hit the nail right on the head. The source is enclosed in a stainless steel pipe that comes up out of the center of the field right here and you will see that here on this corner of the field is a control house. Now, the control house has a cable going underground to the stainless steel pipe, and we enter the field and we wind the source down into a lead shield, what we call a lead pig down in the ground and then it is safe for workers to

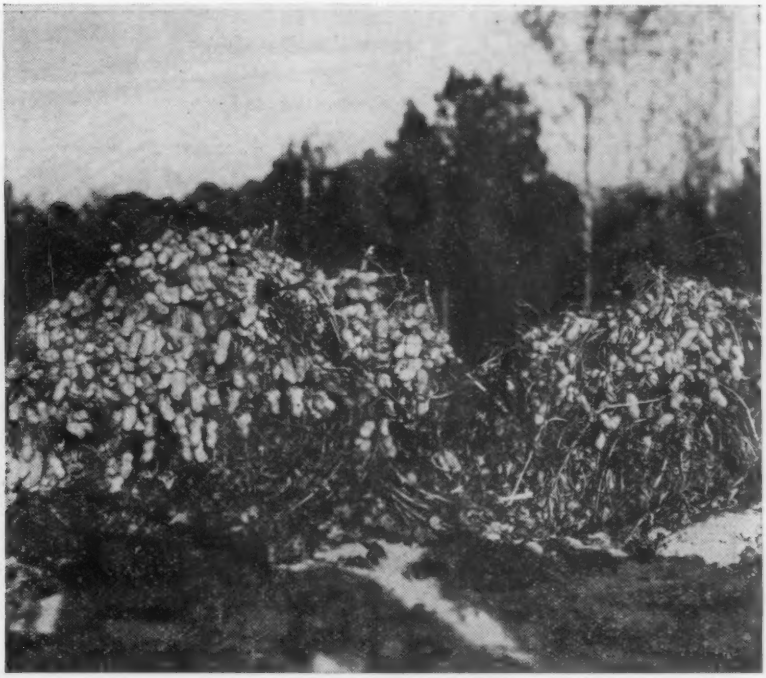

EXHIBIT 18.—Superior-yielding peanut variety (left) produced by radiation. Control at right. North Carolina study.

enter the field. This is put down at a regular time each day, I think 4-hour intervals the source is down and we do all of our cultivating and pollinating and looking at plants in that time and the other 20 hours of the day the source is up.

We have the source here and then we grow the plants in these circles around the source. Of course, the nearer the source you get the greater intensity of the radiation and just like light it is inversely in proportion to the square of the distance from the source. This is an extremely potent source we have.

The carnation plant which I am going to tell you about was grown at 12 meters from the source and that in 2 days would get a lethal dose for a man. Plants are much more resistant to radiation than man.

Now, I can show you some of the results we have obtained, and how we think we know now how to produce these mutations in great abundance. What radiation does is to increase the spontaneous mutation rate. These changes are going on all of the time and have been going on for centuries, since time began, or we had any living matter, and we have had changes and that is how we got our evolution. What we can do with radiation is step up the changes.

Representative HINSHAW. I think that is important to explain, at this point, at least for the record. You say that this radiation has been going on since time began?

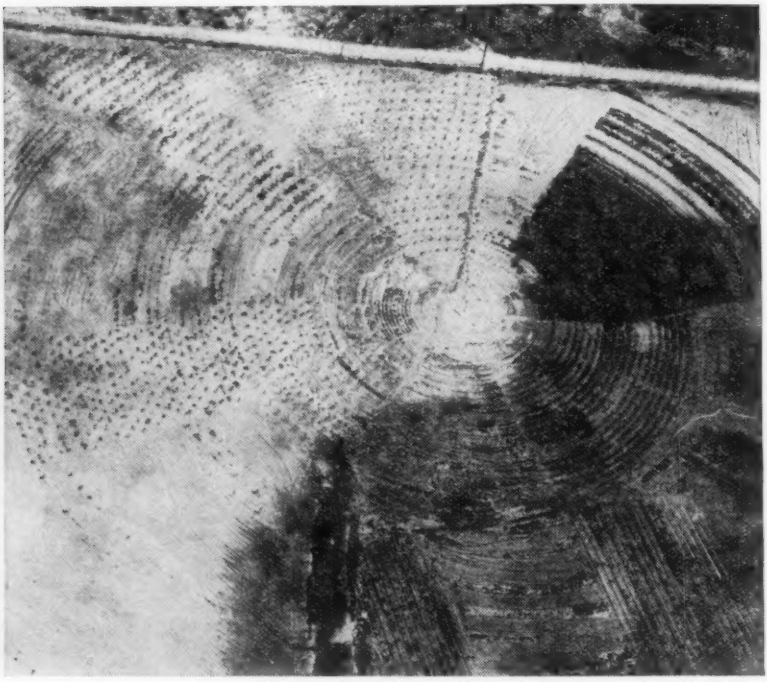

EXHIBIT 19.—Gamma radiation field showing horticultural crops planted in left half of field.

Dr. SINGLETON. Well, I mean the mutations, and, of course, we have had some radiation but mutation has been going on since time began. That is how, since we had any living organisms on the earth, there have been these mutations, and some of them have been beneficial and have been propagated and others have been harmful and have been cast aside.

Representative HINSHAW. I think it would be beneficial for the record, perhaps, to explain the effect of cosmic radiation on mutations. Of course, it is something that cannot be directly measured, but cosmic rays do enter the earth's atmosphere and proceed to the earth and occasionally cause the change in the genes in the same way that this other radiation does it.

Dr. SINGLETON. That is right. Undoubtedly, some of our spontaneous mutations are caused by cosmic radiation, but the scientists who have conducted experiments do not think that there is enough cosmic radiation to account for all of the mutations that have occurred. We do not know yet, and we are still looking for the answers as to why we get all of the spontaneous mutations we do get. They have been going on and they are going on and what we do with radiation is to step up the rate.

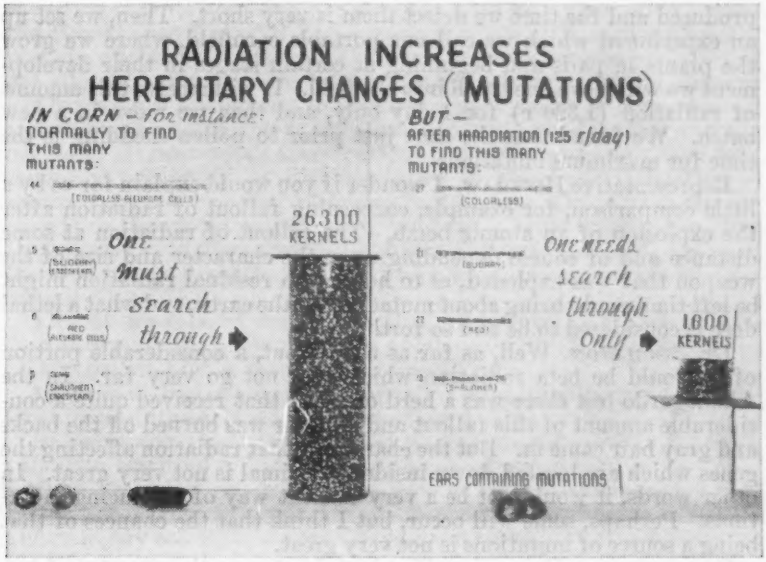

EXHIBIT 20.

Now, I think I can illustrate that with this cylinder of corn. (See exhibit 20, above.) This cylinder of corn has, I think, some 26,000 kernels in it. Now, without radiation, in order to secure these few mutations we have here, 12 of the colorless, 5 sugary, 8 red, and 3 shrunken kernels, you would have to look through this many kernels, more than 26,000 in this large cylinder. However, if you give the right amount of radiation at the right time and you look through only 1,600 kernels as you see here, you would get the following figures. Whereas we got 12 of the colorless from 26,000 seeds of the control, we get 32 from the 1,600 radiated sample and whereas we had 5 sugary we get 35 and where we had 8 red, we get 26 following radiation, and where we had 3 shrunken, we get 17.

Now, these mutations were produced by putting the corn plants in the radiation field at just the right time, and there is an amusing incident in connection with this. This all arose as a result of an accident the previous year. Our workers are always instructed when they go into that radiation field they have to lower the source before they can go in. They take a reading on the meter to make sure there is no radiation. What they did not do for a weeek the previous year was to check the meter when they came out, and actually there was no radiation present for a week. There is a drum about the size of this cylinder out near the stainless steel pipe and the cable that raises the source had slipped off, so what we were doing when we presumably were raising and lowering the source was running the cable back and forth underground and not touching the source.

It was not harming anybody, even the plants. So, we found that from that accident the interval between the time these mutations were

produced and the time we detect them is very short. Then, we set up an experiment which we call our portable cornfield, where we grow the plants in pails and beginning at certain stages in their development we will move one batch into the field. It will receive this amount of radiation (1,320 r) for 1 day only, and then we move in a new batch. We found that the time just prior to pollen shedding is the time for maximum mutations.

Representative HINSHAW. I wonder if you would explain for us by a little comparison, for example, concerning fallout of radiation after the explosion of an atomic bomb. The fallout of radiation at some distance and of course depending upon the character and size of the weapon that was exploded, as to how much residual radiation might be left that would bring about mutations on the earth, and what a lethal dose is considered to be and so forth.

Dr. SINGLETON. Well, as far as the fallout, a considerable portion of it would be beta radiation which does not go very far. In the Alamogordo test there was a herd of cattle that received quite a considerable amount of this fallout and the hair was burned off the backs and gray hair came in. But the chances of that radiation affecting the genes which are located down inside the animal is not very great. In other words, it would not be a very efficient way of producing mutations. Perhaps, some will occur, but I think that the chances of that being a source of mutations is not very great.

Representative HINSHAW. That is right close to the site of the blast and it is not at any distance. I know there has been some concern that there might be a fallout in Japan of enough to do some damage and I do not believe that that is possible.

Dr. SINGLETON. I do not think there have been any mutations picked up or certainly they haven't been in Alamogordo on cattle. It is too early and generations come slowly, and the Atomic Bomb Casuality Commission has not found any in the Japanese people. Of course, you have to carry these on for more generations.

Representative HINSHAW. That is as a result of the bombs on Hiroshima and Nagasaki, and no noticeable mutations have occurred at all.

Dr. SINGLETON. No, the only noticeable effect they think there may be a little bit of difference in the sex ratio. There were fewer male babies than female babies, but they aren't sure of that. It will take generations before they can pick up recessive mutations. So I think the chances of that producing mutations are not very great.

Representative HINSHAW. As a matter of fact, apparently they are quite small. It is almost undetectable, at least some of those things you are not sure whether you have detected a mutation in the animal life or not.

Dr. SINGLETON. It would be a little hard to see how you would get many mutations from such a small amount of radiation. We have found in corn that below 20 or 40 roentgens per day you just don't increase your radiation mutations over spontaneous rate and that rate is fairly high.

Representative HINSHAW. I see you have marked on your scale 1320 roentgens for 1 day only. That is a very powerful amount; is it not?

Dr. SINGLETON. Yes, that is more than a lethal dose for a man. The lethal dose is somewhere between 500 and 1,000, I believe, so this

radiation that we are using has got to be used with care. But I think the Brookhaven National Laboratory is where it is used with care; it is one of the safest places in the world to work because you are just not allowed to do anything where you are getting radiation damage.

Also, we are attempting to produce higher yields in corn through radiation induced shorter plants, thus yielding a greater ratio of grain per stalk. It is now well known that all the grain sorghums have been converted previously by workers mainly in Texas and California to shorter types by use of spontaneous mutations. Yields have not declined; to the contrary they have increased. Thus there is the hope that shorter corn plants might produce a higher grain yield. Some of these short type plants have already been produced by radiation. (See exhibit 21, p. 54.)

This is the type of corn plant that we believe may have a large future because by proper spacing of plants, I think we can develop yields that are higher than those in the tall corn.

Much as we like to sing about the tall corn, I think it may have outlived its usefulness, if we are after grain yields alone.

In sweet corn we have initiated a program to produce types resistant to bacterial wilt, a serious disease of white corn.

There are many important crops, such as apples, which are not normally propagated by seeds but are reproduced by means of grafts and you may ask what we are doing about these. At Brookhaven we are doing a great deal about them.

We have a field, known as the gamma field, which is a 10-acre field with a very large source of radioactive cobalt at its center. Working in conjunction with 8 universities and agricultural-experiment stations, we have many different kinds of trees, shrubs, and vines growing in this field. They are continually subjected to this radiation and we are sure they will produce many abnormal branches bearing strange fruit.

These altered shoots will be cut off and grafted to normal trees at the interested experiment stations and the desirable mutations separated from the undesirable ones there. This program has been going less than a year but already there are more results than we had any reason to hope for.

Our best example is the production of a red carnation on a white flowering plant. This in itself is not economically important but if it can be done with carnations, there is every reason why it can be done with other plants, although on wood plants, like apples, the results will come much more slowly.

This is the 1953 version of the gamma fields, in which we have enlarged the field to 10 acres in extent. (See exhibit 19, p. 50.) And now you can see that this sector of the field is planted to a large variety of horticultural crops, apples, peaches, grapes, berries, and all kinds of things. We even have pine trees and sugar maples.

What we are looking for in this program are mutations, bud mutations—mutations that may occur only on one bud in a single plant, and then we can propagate from that.

In this same program where we grow these horticultural crops, I grew a few carnations, and I think our carnations have told us in 1 year what we can expect from other crops. This carnation was grown in the radiation field last year and received 340 roentgens per day. (See exhibit 22, p. 55.) It started out as a white variety of carnation,

EXHIBIT 21.—Short corn plants at right, typical of radiation-induced types. Higher yields may result from use of shorter strains.

and you will notice that here we have one flower that is completely red, and that arises from a branch away down near the base of the plant.

This plant was taken out of the field in the fall when frost came and allowed to develop in a greenhouse all winter. It produced this branch which gave rise to this solid red flower. We had only two plants that were in the high radiation area that got moved into the greenhouse. Both of those plants had a branch that was all red; that is batting 100 percent.

EXHIBIT 22.

We don't expect to bat 100 percent on all of these. We do feel that what has happened in the carnation will also happen in apples and pears and all of the fruits.

Representative HINSHAW. Well, Dr. Singleton, just to bring a little levity into the situation, when you get so that you can grow a green carnation, you will have solved the problem for the Irish.

Dr. SINGLETON. You know the florists got ahead of us on this. I was in the florist's greenhouse where they grow these carnations on Long Island, which is quite a florist area, and here just before Saint Patrick's Day they had big cans of carnations, and they were all green. They had been put in dye. They beat us to that one.

As you will recall, the Golden Delicious apple came from a single bud mutation. And, I think Stark Bros. paid $5,000 for that one branch of that one tree.

These occur at a slow rate, spontaneously. What we can do with gamma radiation is make them occur. These changes occur almost at will. So you can see why I think we are on the verge of a new era in plant breeding through the use of radioisotopes and the radiation that has come about with the advent of atomic energy.

There are many other programs in radiation genetics, both fundamental and applied, in various universities and agricultural experiment stations in other parts of the country. In Nebraska there is a

program to develop a winter hardy barley. In California poultry breeders are using radiation to increase egg production.

Previous radiation studies with the fruitfly indicate the poultry program will be successful. The principles of genetics are universal from bacteriophage and bacteria to man. At the Oak Ridge National Laboratory an extensive radiation study is being conducted with mice. Information gained in this study will provide data necessary for the use of radiation in animal breeding.

Since resistance to diseases and higher yields can be induced in plants, why not in animals? Instead of putting corn pollen in the pile, why not put spermatozoa of cattle, sheep, or swine in the pile? The semen so treated could then be used for artificial insemination, and perhaps resistance to erysipelas in swine or brucellosis in cattle might be "created" in the same manner as disease resistance in plants has been "created."

Perhaps sheep with improved wool might come from such a study. Undoubtedly, there are many technical difficulties that must be overcome, but the work with plants suggests a similar approach with animals might be successful.

One of our most experienced animal breeders, Dr. Winters at Minnesota, who was a colleague of mine when I was on the faculty in 1941, is enthusiastic about this proposal, and it seems most likely a cooperative project will be initiated.

I have tried to present briefly some of the accomplishments of atomic energy in creating new disease resistant varieties of plants, also higher yielding types. These have been produced in a short time and with limited expense.

I think we should emphasize the short time. This carnation was developed in 1 year, and we can expect other things will be developed in this short time.

Success in these preliminary experiments seems to justify the use of radiation genetics on a much wider scale in plant and animal improvement.

I hope you will agree with me that if atomic energy lives up to its promise in the creation of disease resistant and higher yielding plants as well as producing superior types of animals, it will have established itself as a boon to civilization.

Representative HINSHAW. Thank you very much, Dr. Singleton.

Now, I am very much interested in this subject of mutation. How much radiation do you find in total number of roentgen-hours required by a given plant or by a particular type of plant to bring about mutation?

Dr. SINGLETON. Well, it depends upon the stage at which it is given. Actually, these plants produced an ear of corn from 1 day of irradiation. One day only at the critical time is sufficient to produce all of these mutations. We had these plants and they received radiation only for a single day. We moved a batch in, and when they came out, another batch went in so that for a period of 21 days we had plants that received radiation at certain stated times.

They only received radiation for 1 day. So it doesn't take long, and if you get the critical time, it can be done fairly easily.

Representative HINSHAW. It would appear that you can create approximately 75 to 100 mutations through this atomic pile source to 1 that is created normally.

Dr. SINGLETON. Oh, yes; the ratio would be even higher than that. The ratio in corn is probably, I guess a ratio of 100, 3 per 10,000 would be a fairly good ratio for spontaneous rate. And we get these 3 to 4 per 100 which is a factor of a hundred.

We can make those occur at least 100 times, and for some genes probably more. Some genes mutate more frequently than others, and there is considerable variation there. (See exhibit 23 below, and exhibit 24, p. 58.)

Representative HINSHAW. We thank you, indeed, for your presentation, Dr. Singleton, and we hope to see you at the Brookhaven Laboratories before very long.

Now, Dr. Bugher is here, and I think we would be very much interested in hearing a brief discussion of the possible effects of radiation fallout. That seems to be a subject which is very interesting to the press, and Dr. Bugher is entirely qualified to speak on this subject.

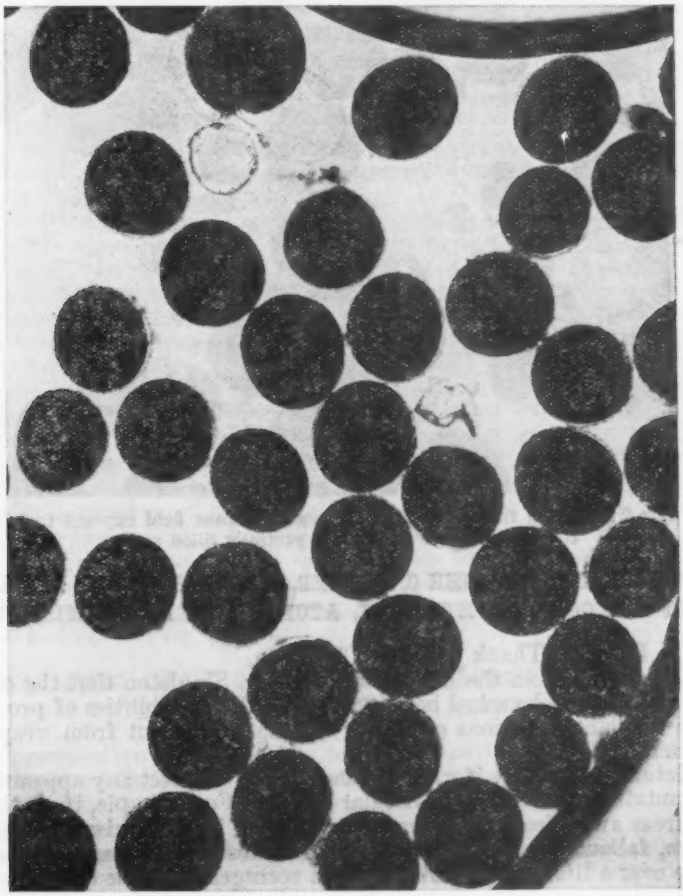

EXHIBIT 23.—Normal corn pollen, from plant that has not been irradiated.

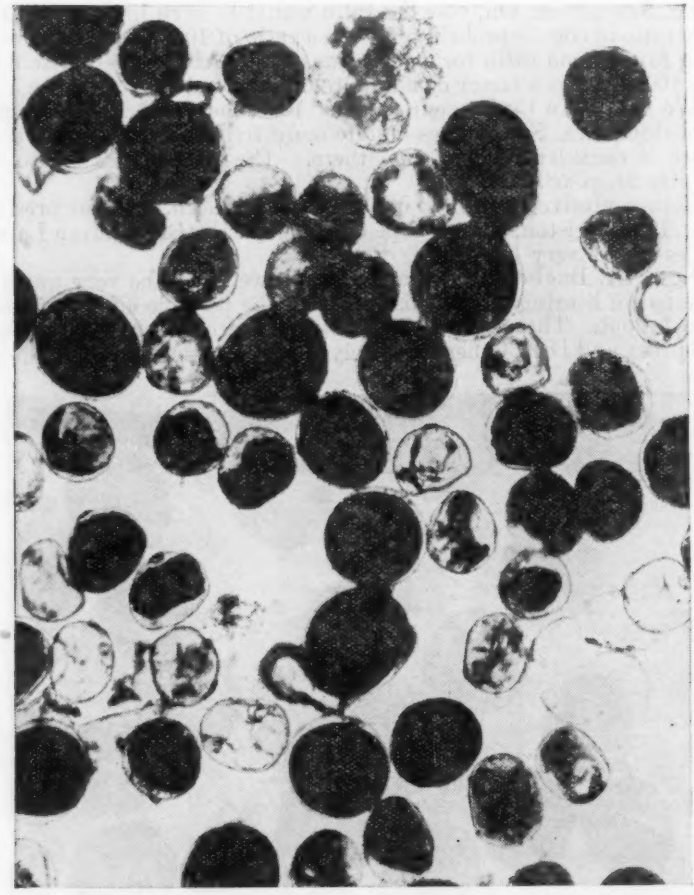

EXHIBIT 24.—Pollen from corn plant grown in gamma field exposed to 1,320 r. for 1 day. Note empty and partially filled grains.

STATEMENT OF DR. JOHN C. BUGHER, DIRECTOR OF THE DIVISION OF BIOLOGY AND MEDICINE, ATOMIC ENERBY COMMISSION

Dr. BUGHER. Thank you, Mr. Chairman.

I gathered from the discussion with Dr. Singleton that the question which is to be asked here is what are the possibilities of production of plant mutations or injury in areas of fallout from weapons detonations.

Actually, probably it would be impossible to detect any appearance of mutations due to that particular source. For example, if we think of areas away from the Nevada test ground in particular, the maximum, fallout any place in the United States will give an integrated dose over a lifetime of a fraction of a roentgen with the exception of

some small areas very close into the proving ground. It is a fraction of a roentgen.

Now, I didn't quite hear the figure that Dr. Singleton gave for the production of mutations with respect to the dose rate, but I believe that it is somewhere in the thousands of roentgens to produce a doubling of the mutation rate.

Dr. SINGLETON. It was about 1,300 in 1 day.

Dr. BUGHER. So that the magnitudes are tremendously different here.

Representative HINSHAW. Thirteen hundred for 1 day versus a fraction of one over a lifetime.

Dr. BUGHER. That is available; yes. So that the only way we have found it possible to assess the weapon effect on plants with respect to mutations is to move in right under the detonation itself and observe the plants that survive in the perimeter of the immediate detonation area.

There is work going on out in Nevada along that particular line to see what can be detected in regard to the quantitative frequency of mutations in the desert plants that are right under the bomb.

Representative HINSHAW. I thank you for that presentation, and I think that we have gone into it about as carefully as we can at this time.

If there are any other questions, I know that the press gentlemen will be delighted to consult you and get more extensive information.

Thank you very much.

Now, the next witness that will appear before the committee is Dr. E. C. Stakman, professor of plant pathology at the University of Minnesota. Dr. Stakman is a member of the National Academy of Science. He received his bachelor of arts degree at the University of Minnesota, and he has an honorary doctorate of science from Yale University, the University of Rhode Island, and also the University of Halle in Germany. He is a consultant to the Rockefeller Foundation and to the Division of Biology and Medicine of the United States Atomic Energy Commission, also a member of the board of the National Science Foundation, and was president, American Association for Advancement of Science, 1949. He has been a delegate to several international congresses on plant disease.

He is a member of the United States National Commission and Executive Committee of UNESCO. He was a member of the Scientific Mission to Japan in 1951. He is known for his extensive investigations and is the author of many publications on cereal rusts and smuts.

Dr. E. C. Stakman.

STATEMENT OF DR. E. C. STAKMAN, PROFESSOR OF PLANT PATHOLOGY, UNIVERSITY OF MINNESOTA

Representative HINSHAW. We are delighted to welcome you here and to receive the important information which we know you have to give us.

Dr. STAKMAN. Thank you.

Like all the people who have preceded me, I certainly appreciate the opportunity of appearing before this committee. I especially

appreciate the opportunity of talking about plant diseases, not because I like to talk, but because plant diseases are so tremendously important.

I don't think that anybody could have listened to the presentations that were given yesterday and today, without being amazed at the progress that has been made in understanding more about plant and animal growth and reproduction through the use of radioactivity.

Nevertheless, we should stop to think of this fact, that after the scientists have done everything they can to tell the farmer how to grow good crops, and after the farmer has done everything that he can to try to grow good crops, there still are two tremendously important hazards over which farmers and scientists have only limited control: bad weather and plant diseases and certain insect pests. Even the hazards of weather have been overcome to some extent and probably will be overcome more by the use of radiations.

The hazards of weather have been overcome somewhat by producing early maturing, drought resistant and heat resistant varieties. And the technique that Dr. Singleton has just described for the production of new varieties by mutation give promise of making further progress in this field.

As concerns plant diseases and certain kinds of insect pests, man certainly has not yet completed his conquest of nature, because plant diseases alone cause a loss of approximately $3 billion a year, according to Dr. Singleton, in the United States.

I am very glad to hear that figure given by a geneticist instead of a plant pathologist because plant pathologists often are accused of overestimating the losses caused by plant diseases. But if you take the direct destruction of diseases plus the cost of control measures, I think that the cost may even exceed $3 billion a year.

There are some diseases that are annihilating, such as the chestnut blight which has almost eliminated the chestnut from the United States. And there are others that are devastating, such as the cereal rusts, which may destroy up to two-thirds of the crop of wheat and oats in extensive areas, and potato blight which can almost completely destroy potatoes in the field or in storage.

There are other diseases that are debilitating but not conspicuous, because they cause seedling blights, root rots, wilts, and various other kinds of diseases that are recognized easily only by experts, but which nevertheless cause extensive damage. There are still others that are disfiguring, such as apple scab, potato scab, and many others.

Plant diseases are insidious and destructive for a number of reasons: (1) Because of the relative invisibility of plant disease organisms; (2) because of their prolificacy; (3) because of their genetic variability; and (4) because of the rapidity with which many of them can spread. Plant diseases are caused principally by viruses which are not visible at all, even under the microscope; by bacteria, which are extremely small; and by fungi of various kinds which are the largest of the three. But even many of the fungi are so small that a single spore (fungus seed) measures only about one four-thousandths of an inch in diameter.

Plant disease organisms can multiply with amazing rapidity. For example, in this flask there is a very large forest of the corn smut organism which is growing on potato mush which has been solidified by a gelatine-like agar.

This forest or fungus colony started about 3 weeks ago from a single cell, about one four-thousandths of an inch in diameter; and it now has a population of approximately 2½ billion individual unicellular corn-smut plants. There are approximately the same number of cells in this flask as there are people in the world. The genetic variability is illustrated by the fact that the smut in each flask looks different, but all were derived by mutation from a common ancestor.

Such small objects, of course, can be disseminated very widely and quickly by the wind; they can be disseminated as far as the wind blows. We often catch 1 million spores of wheat stem rust per square foot in a 24-hour period. And, if each one of those million spores caused infection, each one could produce within about a week 450,000 additional spores; and there would then be 450,000 million, 450 billion, of these spores in a square foot of a wheatfield.

So that we are fighting an invisible world of plant-disease microorganisms all of the time.

There are several general methods of control: cultural practices; the eradication of certain alternate host plants, such as the common barberry, buckthorn, and red cedar; the use of chemical fungicides, substances which when applied to the seed in some cases or when dusted or sprayed onto the growing plants kill disease organisms or prevent them from germinating and entering the host plant.

Many of the most destructive diseases of the most important food and feed crops in the United States, and in the world, however, cannot be controlled by these methods. Consequently, the only recourse is to try to develop crop-plant varieties that are resistant to them.

Dr. Singleton has indicated one way in which resistant varieties can be produced.

The greatest barrier to the development and maintenance of disease-resistant varieties is the complex composition of plant-disease organisms. A single species may comprise hundreds, or even thousands, of parasitic races which cannot be distinguished by looking at them under the microscope but only by their effects on crop plants.

I have here for example five kinds of corn smut, which I use as an illustration. I think you can see that all five are quite different in appearance. This one may cause small galls about the size of a buckshot on corn, this one about the size of a hazelnut, this one about the size of a walnut; and what we are trying to find out is whether any of them can produce galls the size of a coconut. We are trying to find out what the maximum virulence can be.

I want to emphasize this fact: While man is trying to produce disease-resistant plants, nature is producing new and virulent strains or races of these plant-disease organisms.

I want to illustrate the practical importance of new parasitic races by giving a very brief history of the attempt to produce and maintain varieties of wheat resistant to stem rust, the most destructive of all cereal diseases in the United States. After a very devastating epidemic in 1916, when about 300 million bushels of wheat were destroyed in the United States and Canada, farmers in the spring wheat area started growing durum wheats, because they were resistant to rust; but they retained their resistance for only about 5 years. At the end of that time they became completely susceptible because a new race of rust appeared.

Then hybrids were made, and one known as Ceres was introduced in 1926. It lasted only until 1935, and in that year it was badly damaged by still another one of these parasitic races of rust, designated as race 56.

By 1938 several other varieties had been developed that were resistant to the parasitic races of the wheat-stem rust which were then widely distributed and prevalent in North America. These new hybrid varieties remained resistant from 1938 through 1949. In 1950, however, still another very destructive parasitic race of the rust, 15B, appeared and swept over the country on the wings of the wind. It had been present, especially on or near barberries in Pennsylvania and Virginia, for about 10 years, but had never been widespread. In the spring of 1950, however, it swept southward and westward, then northward from Texas on into Canada. All of the varieties that had been produced by 45 years of breeding were completely susceptible to this new parasitic race of rust, 15B, which is now the principal race in the United States.

As an indication of the destructiveness of this rust, two-thirds of the macaroni or durum wheat in Minnesota and the Dakotas was destroyed in 1953. Fields of durum that promised to yield 18 to 25 bushels of 60-pounds-to-the-bushel wheat actually yielded only 6 to 8 bushels of about 54-pound wheat, and many fields were not worth harvesting. The total production of durum was only 13 million bushels instead of the 40 million needed for domestic consumption.

The durum varieties that had been grown, as I said, had been resistant between 1938 and 1950, but they have no resistance whatsoever to this new race, 15B. The bread wheats that had been resistant also are susceptible, and in 1953 approximately one-fourth of the bread wheat crop in Minnesota and the Dakotas also was destroyed by this race of stem rust.

Extensive attempts are being made to develop varieties that are resistant to race 15B, also, but we already know about 275 races and it is not easy to develop resistance against all of them.

Now, I would like to show how the use of radiations helps to find out what the maximum virulence is that nature can put into some of these plant-disease fungi while we are trying to find out at the same time how much resistance man can put into crop varieties.

I have taken corn smut as an example, because it can be grown like this in flasks on artificial media. You cannot do that with rusts; consequently genetic changes are not so easy to demonstrate.

At Minnesota we set out a few years ago, in cooperation with the Atomic Energy Commission, to try to find out what effects mildly radioactive substances, such as salts of polonium and uranium, would have on mutation in corn smut and many other plant-disease fungi. Starting with two single cells of corn smut, one four-thousandths of an inch in diameter, we have obtained about 15,000 different strains or races of the smut which differ, as you see them here. All were derived from the original 2 cells by mutation and intercrossing. The question obviously is this: Are mutants weaker or are they stronger in some respects than the parents?

We selected 198 mutants, all derived from the progeny of a single cell, and studied loss or gain in 13 characters. If there was a gain in 7 characters and a loss in 6, the deviation was plus. We simply took the algebraic sum of the losses and gains.

For 13 characters in these 198 lines, approximately 60 percent had neither a net loss or gain, about 20 percent had a net loss, and about 20 percent had gained something. This one, for example, has obviously gained in color because this one is light in color and this one is black. The important thing, of course, is that occasional mutants gain in virulence also.

Although this looks as if it might not have immediate practical applicability, studies of this kind are essential because it is essental to learn how many of these new and virulent races can be produced. If we were to let nature take her course, we might have to wait 25 or 50 years to find out what we can find out in a relatively short time when we speed up the process of mutation by the use of radioactive chemicals. We already know that we have to breed against a tremendous number of these parasitic races and that new ones are continually being produced.

We are trying to find out the maximum virulence that nature can put into these pathogens in relation to the maximum resistance that man can breed into crop varieties.

What are the procedures in breeding against such a tremendous number of different races of such fungi as this? One method is to introduce varieties from other areas, in the hope that they will have resistance to a number of these different parasitic races. The second method is, of course, hybridization, as I think you all know: A variety that has desirable agronomic characters is crossed with varieties that have rust resistance to many races and then those that have the best combinations of characters are selected.

One difficulty in breeding is that there sometimes is a linkage between good characters and bad ones. As one example, a variety was produced in Mexico recently which was highly rust resistant, but it had very weak necks—that is, the stem just below the head of the wheat was very weak. The necks were so weak that the variety might have been called Limber neck. In hot or windy weather about 40 percent of the necks broke, and the heads fell to the ground. In these crosses rust resistance and limber neck were always inherited together; the good character of rust resistance was always linked with the bad one of weak necks.

In certain other crosses between a variety with considerable rust resistance but poor agronomic qualities and rust susceptible but otherwise good varieties, there is linkage between the rust resistance and extreme susceptibility to a bacterial disease known as black chaff. This linkage has never been broken; the good is linked with the bad.

There is a similar linkage in certain crosses between resistance to crown rust in oats and extreme susceptibility to a very devastating blight.

Dr. Singleton probably will agree with me that one of the greatest services that radiation can render will be to break these linkages so that good characters can be separated from bad ones; and the good characters can then be recombined without having to take the bad with the good.

Just as radiations may induce the development of virulent mutants of fungi, disease-resistant mutants of crop plants may be produced, as Dr. Singleton pointed out, by radiation. They have succeeded in producing a variety of oats which is at least resistant to some rust races.

Peanuts with resistance to leaf spot have been reported, and there is evidence that mutants with resistance to a blight in oats were produced by radiation.

Dr. Singleton mentioned also that a certain induced mutant of corn has at least a high degree of resistance to one of the devastating leaf blights caused by a fungus with the very euphonious name of *Helminthosporium turcicum*.

Let me emphasize this: In this kind of work with resistant varieties the attempt is to find out what may happen in the future. It, of course, is rather disconcerting to find that supervirulent races of plant-disease fungi and bacteria can be produced. But if we look forward 25 or 50 years, we simply have to know what it is that we are breeding against. If we do not know the possibilities, we are going to have the same experience that we have had in the past—varieties retaining their resistance at some times and in some places, and then succumbing to a new virulent race of the plant-disease organism. There is a much greater chance of safeguarding the future if we know what kinds of parasitic races nature is likely to produce.

Many other examples of this sort of thing could be given. I have taken stem rust of wheat as an example, because it is a good one, particularly when supplemented with the data on corn smut.

Radioactive substances can also help greatly in developing better fungicides. Let us assume that it is going to be difficult to produce a variety of wheat or oats or barley that is universally or highly resistant to rust and that it will be necessary to apply fungicides also in order to help control the rust, to combine the use of a semiresistant variety with the application of a fungicide. Stem rust and most other rusts can be controlled if plants can be dusted often enough with sulfur. But to dust 70 million acres of wheat in the United States with the minimum amount of sulfur that would be effective in years when weather favors rust would require about 1¾ million tons of sulfur, to say nothing about the cost of airplane dusters or other kinds of dusters that would be necessary to apply the sulfur. Consequently, better fungicides are needed to supplement the services of resistant varieties. We need fungicides that are much more effective and cheaper than those now available.

Fungicides are needed that get inside the plant, stay there for some time, and thus have a systemic fungicidal effect. If, for example, grain seed or potatoes could be treated with some substance which would be taken into the plant and prevent infection or prevent the development of plant-disease organisms after they once are inside the plant, it would be a great advance in plant-disease control. The best way of finding out the possibilities is by the use of tracer elements—that is, tagged chemicals, so that it can be determined whether or not they go into the plant, where they go in the plant, what they do in the plant, and how long they last. One of the things that is most badly needed at the present time is a systemic fungicide which can be used in small quantities, which does not have to be applied every week or 10 days, which will go inside the plant and control certain diseases which at the present time cannot be controlled. Some tree diseases, certain diseases of high-priced ornamentals and many others cannot be controlled by any methods now known. All that can be done in many cases is to destroy diseased plants in order to protect healthy ones.

But that is rather drastic treatment, to kill the patient in order to prevent the disease from spreading.

If we can develop fungicides, and progress has been made, which can be put into a tree, or which can be put on the seed of annual plants, or which can be applied as a spray or dust once or a few times during the season, there would be protection at low cost. The yields of many of our crops could be increased by 25 or 30 percent, and in some cases even more, if such fungicides were available.

I have tried to explain three ways in which radiations are useful in studying and controlling plant diseases. First, radiations are useful in finding out the maximum virulence of plant-disease organisms, so that we may know what to breed against in producing resistant varieties of crop plants; second, in attempting to increase the number of resistant varieties by speeding up the process of mutation, compressing into a short time what would take much longer under natural conditions; and third, in the developing of new and more effective fungicides.

I have not said anything about the great services that isotopes are rendering in helping to understand plant-disease processes. There is not time to go into that, and it would be very technical in any case.

I would like to summarize, however, by saying that the degree to which we overcome the menace of plant diseases will depend on the depth of understanding we can obtain, not only of crop plants but also of plant-disease organisms and the interrelationships between the two. That requires basic research.

In the 45 years during which I have been studying plant disease, I have come to the conclusion that basic research is the cheapest in the long run, because it leads to understanding, which is an absolutely essential basis for progress in plant-disease control. Plant pathologists and other scientists in this general field did not necessarily engage in basic research because they wanted to. They wanted to get quick results. But they have been driven to basic research because they have been frustrated so often in trying to find permanent solutions to many problems by mere empirical testing.

Basic research or fundamental research in this general field is not a luxury for scientists. It is a stern practical necessity if we are to look forward and really counteract the menace of plant-disease fungi. I could say the same thing about insects. I would like to say also that among the best tools for finding out necessary facts are radiations and tagged elements.

Thank you.

Representative HINSHAW. Thank you very much, indeed, Dr. Stakman. Are there any questions that you would like to ask, Mr. Durham?

Representative DURHAM. Doctor, you kind of scare me on this mutation thing. There is one thing I would like to ask you. At the present time do you have any knowledge as to how much is being spent on basic research in this field. Could you give us an estimate?

Dr. STAKMAN. I am sorry I cannot. I think some figures on basic research in general are available in the National Science Foundation.

Representative DURHAM. Since you said this was fundamental in this control, I was wondering as to the difference between what is being spent on basic research and what is being spent on chemical

methods of trying to control these diseases. Could you give me some idea? I have an opinion that probably much more is being spent and being advertised over the television, radios, and newspapers on chemicals and other control substances which go into this control of plant diseases than is being spent on basic research.

Dr. STAKMAN. Yes; I am sure of that. I have seen figures on the amount of money being spent on basic research in the United States, but I would rather not attempt to give the figures offhand of each dollar spent for research and development, probably not more than 10 cents is spent in basic research.

As concerns basic research in agriculture, in the Department of Agriculture and in the Agricultural Experiment Stations, I can simply say this: I know we are not doing enough of it. We have been so busy putting out fires, meeting emergencies, that there has not been time enough to devise new fire-fighting apparatus.

Representative DURHAM. I think we could get some figures which I would be interested in hearing, Mr. Chairman.

The other thing I would like to ask is which is the most difficult in your opinion to control, the virus type of disease or the bacteria, or the other types, fungi, and things of that nature?

Dr. STAKMAN. Each group has certain very vicious ones and certain relatively innocuous ones. If you take into consideration the principal food crops, the principal economic crops in the world at the present time, wheat, corn, rice, potatoes, and so on, fungi probably cause the greatest damage.

Representative DURHAM. Is it more difficult to control than the virus type of disease?

Dr. STAKMAN. In some cases it is; in others it is not. Cereal rusts and certain other fungus diseases are hard to control because the wind spreads them so fast and they attack crop plants that are grown on large acreages, with many plants per acre, so that epidemics can spread fast and far. Viruses are not spread by the wind but principally in propagative parts of plants or by insects. Some viruses can be controlled by selecting virus-free propagative stocks, increase from that, and thus establish virus-free lines. You can start with a single virus-free potato tuber. This can be done also with some small fruits and tree fruits. But this is not feasible in some cases, such as curly top of sugar beets, the virus of which is spread by insects that live not only on beets but also on wild plants from which they may carry the virus to beets.

Representative DURHAM. We ordinarily think of virus acting very fast in the human body. What is the action in these plants?

Dr. STAKMAN. Some of the viruses that attack plants are rather slow acting, and are very insidious. Others act fast. The incubation period of some of them is only about a week. The incubation period of others is several months or longer. So it depends upon the virus and the particular plant that it is attacking. When I say that the fungi are the most destructive, I must add that knowledge regarding viruses in plants is just really beginning to accumulate. Many conditions in plants which appeared to be due to malnutrition or other unfavorable growth conditions are now known to be caused by viruses. Nevertheless, I think it is correct to say that at present the fungi are the most destructive to the principal food crops of the world.

Representative DURHAM. I believe that is all, Mr. Chairman.

Representative HINSHAW. Dr. Stakman, I think for the sake of our record, it would be well to estimate the number of qualified men engaged in the study of plant pathology in this country, and the numbers that are engaged in the study of it in conjunction with the use of radioactive isotopes.

Dr. STAKMAN. Dr. Pearson may have an idea of the number studying in connection with radioisotopes.

Dr. PEARSON. I would say we probably have 10 or 11 or perhaps 15 projects we are supporting in studying plant diseases with radioisotopes. But there are many in addition to this that are being supported by State funds or by funds to the Department of Agriculture. The total of these I would not know, but I certainly would guess it would be 3 or 4 times the number supported by the AEC.

Dr. STAKMAN. I was going to say that the equivalent of about 50 full-time investigators in the United States are making some studies of this type. Very few individuals spend full time, but many spend part time and the equivalent of 50 is, I think, a fair but liberal estimate. Most of those that are concentrating on such researches are collaborating with the Atomic Energy Commission; therefore Dr. Pearson would know the projects and the investigators.

That gives me a chance to say something, Mr. Chairman, that I hope may be considered pertinent. It is my conviction that the Atomic Energy Commission has had broad scientific vision and has required good performance on contracts. It is very gratifying indeed that they are taking a long view of some of these problems. Because if we are too myopic and take only a short view, we are not going to solve some of our most important problems.

Going back to the estimate of the equivalent of 50 or fewer pathologists investigating radiations in relation to plant diseases, there are about 1,600 members of the American Phytopathological Society, not all professional pathologists, but say roughly 1,000 professional pathologists. That would be 50 or fewer out of 1,000.

Representative HINSHAW. That does not seem to be very many.

Representative DURHAM. When you speak of a long-range view, Doctor, you mean the long-range view in basic research?

Dr. STAKMAN. That is right. I am sorry if I frightened you in discussing the danger of plant diseases, although I am glad, too, because we have to keep in mind all possibilities, even the frightening ones.

Representative DURHAM. We are used to that in this committee.

Dr. STAKMAN. If it is pertinent now, I would like to say this: If we consider the possibility of a devastating epidemic of cereal rusts, virus stunt of corn, virus yellows or sugar beets, and of flax rust in 1 year, which could happen if all conditions were favorable for the development of epidemics of those diseases—we would be in real difficulty. I think it should be kept in mind also that, although we are a food surplus country now, many of the countries of the world with whom we are associated are food deficiency countries and we might have trouble in furnishing enough food under certain conditions. It seems to me that we have to be prepared in that respect as well as in other respects.

Representative HINSHAW. We thank you very much, indeed, Dr. Stakman. That is a very interesting and exciting subject which we would like to take longer to go into. I might say we are tempted to come out to the University of Minnesota and look over your plant.

Dr. STAKMAN. It would be a very happy day for us if you would.

Representative HINSHAW. Thank you very much, sir.

The subcommittee acknowledges the presence of the Chairman of the Atomic Energy Commission, Mr. Strauss, and also a member of the Commission, Mr. Campbell. We are honored indeed by their presence here this afternoon to listen to some of this discussion.

We also have with us Mr. Howard Miller, a Representative from the State of Kansas, and our chairman of the full committee, Mr. Cole of New York.

There was present also until a few moments ago, Mr. Hunter, my colleague from California.

The next subject is the role of radioisotopes in the study of milk secretion and animal metabolism. Dr. J. C. Shaw, professor of dairy husbandry in the University of Maryland, will conduct the discussion. He received his bachelor of science degree at Iowa State College, his master of science at Montana State College, his doctorate of philosophy at the University of Minnesota. He was a professor at the University of Connecticut from 1940 to 1945, and received the Borden Award of the American Dairy Science Association in 1947 for research on milk secretion and ketosis in dairy cattle. He is widely known for his research and publications in the field of milk secretion, physiology, and ketosis. Dr. J. C. Shaw.

STATEMENT OF DR. J. C. SHAW, PROFESSOR OF DAIRY HUSBANDRY, UNIVERSITY OF MARYLAND

Dr. SHAW. Mr. Chairman, members of the committee, I am greatly pleased to be here and to have been invited to speak before this group. I feel rather humble finding myself on the same program with a former professor, Dr. Stakman, from the University of Minnesota, who taught we what litle German I knew at one time.

I am going to read my opening remarks, if I may, and then use the charts and a demonstration to present some of the illustrations which I hope to put across regarding the use of tracers in this field of animal metabolism.

The rapidly growing population of our country imposes on us the responsibility of providing a steadily increasing amount of food of high quality in the years to come. This means that in order to maintain and improve our present standards of living and of well-being, we should seek not only greater production but greater economy in the animal industry. The present abundance of foods of high quality—such as milk, eggs and meats—has been brought about by our tradition that has enabled free and happy cooperation between the farmer and scientists. Knowledge gained in the basic biological sciences, such as genetics, nutrition, physiology and biochemistry, has been applied with great successs in the past to practical problems in animal production.

An adequate backlog of fundamental research is needed urgently if this fruitful application of science is to continue. The truth is, we

have very little reserve information on which we can base our future applied research. Such, fortunately, has never been the case. Nor is it entirely due to the rapidity with which we proceed to apply findings in the laboratory to problems on the farm.

By far the greatest reason for this need for basic research is to be found in the very pattern of scientific progress. Each new discovery renders old concepts and methods obsolete. Each new concept not only throws a shadow of uncertainty over the previous views, but often provides the tools to clear up the uncertainty. Such has been the impact of tracer work in biology. Early in the history of tracer work, it was established that the system of checks and balances in life processes is dynamic in nature. The significance of this finding may be understood by means of an analogy. If we look at the army of a nation in peacetime, it seems to be in a ready state. Yet men are being constantly drafted, trained, promoted, discharged, and so on. The personnel is continuously changing. The size of the army can increase or decrease, depending on whether or not more men are drafted than discharged. Now, if we wanted to estimate the potentialities of this army in times of emergency, mere information of the peacetime manpower would not be enough. What we would want to know would be, how rapidly can the army be prepared? How fast can the men be drafted and trained? How rapidly can supplies, etc., be mobilized? Where are the bottlenecks that are holding up mobilization, and how can we overcome them?

In other words, we would want to know the rates at each step, and how we can control or alter these to our advantage. When a cow is pregnant, she goes into an economy of preparedness, so to speak, to get ready to supply milk. When she calves and starts secreting milk, she goes into an all-out emergency economy. In this condition, if she does not get enough calcium, she will take calcium from her own bones to put into the milk. The rate at which she can put out calcium into milk will depend, ultimately, upon the rates at which she can digest and absorb feed calcium, how fast is the exchange of calcium between bone and blood, how fast she can deliver it to the blood, and, finally, how fast the calcium can be taken from the blood and made into milk calcium. Similarly, the rates of formation of milk sugar, protein and fat will also depend on rates of digestion, etc., in the body, and not necessarily upon the amounts that are present in any part of the body at any time. Stockpiling is not observed to a great extent in the body except in a few cases. Finally, the rates at which any or all of these milk components are formed will decide the rate of milk secretion, that is, the capacity of the udder to produce milk.

Therefore, information on the rates of these reactions is not merely of academic interest. It may tell us in the years to come not only how we can improve milk production in the individual animal, but help us in the choice of economic feeds, best management practices, and in choosing the best stock for breeding.

We can extend this to other biological studies, such as in egg laying, and so on. This dynamic concept of the body constituents is relatively new and it is easy to see that we have a completely new approach for studying the various processes of the body, such as digestion, reproduction, milk secretion, and so forth, and it is exciting to imagine the possible benefit that might arise from this approach. For the study of this

dynamic state, radioactive tracers are indispensable. In fact, without such tracers, we could only have speculated upon its existence. Other methods to study this continuous flux of body materials are as inadequate for the purpose as a snapshot camera would be for studying a jet plane in the air. The tracer technique offers us a motion-picture camera, as it were, for the purpose.

Tracers can be used in a wide variety of ways, and you have already heard about some of them. The experience of our group at the University of Maryland may give you an idea of how indispensable and inevitable the tracer technique is becoming in research on farm animals. We have been working on a number of projects of immediate use to the dairy farmer. One of these concerns ketosis, or acetonemia, in dairy cattle. It has been shown at Maryland that cortisone or ACTH, the modern miracle hormones, will bring about dramatic cures of this disease. Since this disease causes huge economic losses annually, we would like to prevent it if possible. Ketosis is caused by a hormonal deficiency, a breakdown in the body's wise system of checks and balances, creating a bottleneck in the metabolic assembly line in the body. If we want to go beyond this, the most direct and profitable approach to study this problem appears to be the tracer method. We have other projects going on, one on bloat in cattle and sheep, a condition that results in losses amounting to millions of dollars, one evaluating the growth hormone, which doubles milk production in a week's time, and one studying the process of fermentation in the paunch of a cow, all aimed to be of immediate help to the farmer. Some of these projects were initiated before the radioactive tracer era, and, indeed, we achieved quite a degree of success in each without radioactive tracers. Yet for us to make more rapid progress in the future we must use radioisotopes. Gradually, our tracer program is expanding, and we are now expecting to use tracers in every one of our projects at some stage.

To illustrate the value of the use of radioisotopes in studies with animals in application to the animal industry, a few illustrations will be cited of research which has been conducted (see exhibit 25, p. 71). Until recently, it has been impossible to determine the true digestibility of calcium or phosphorous in farm animals, due to the fact that both of these minerals are absorbed and reexcreted in the gut. Thus, some of the calcium and phosphorous will pass from the feed directly to the feces and much of it will be absorbed and reexcreted into the gut and appear in the feces. It has been practically impossible to differentiate between the two, and, therefore, we have been unable to give a correct appraisal of the availaibility of calcium and phosphorus in various animal feeds. This is in direct contrast to the organic nutrients, since we can measure the digestibility of organic nutrients by analysis of the feed and the feces by virtue of the fact that when these organic nutrients are absorbed into the body from the digestive tract, they are broken down and not reexreted into the gut. It has been possible to determine the amount of calcium and phosphorus which is reexcreted into the gut by injecting radioactive calcium or radioactive phosphorus into the bloodstream. By this method it has been possible to establish how much calcium and phosphorus from a given feed passes through the digestive tract without being absorbed and thus can give us an accurate measure of the availability of calcium and phos-

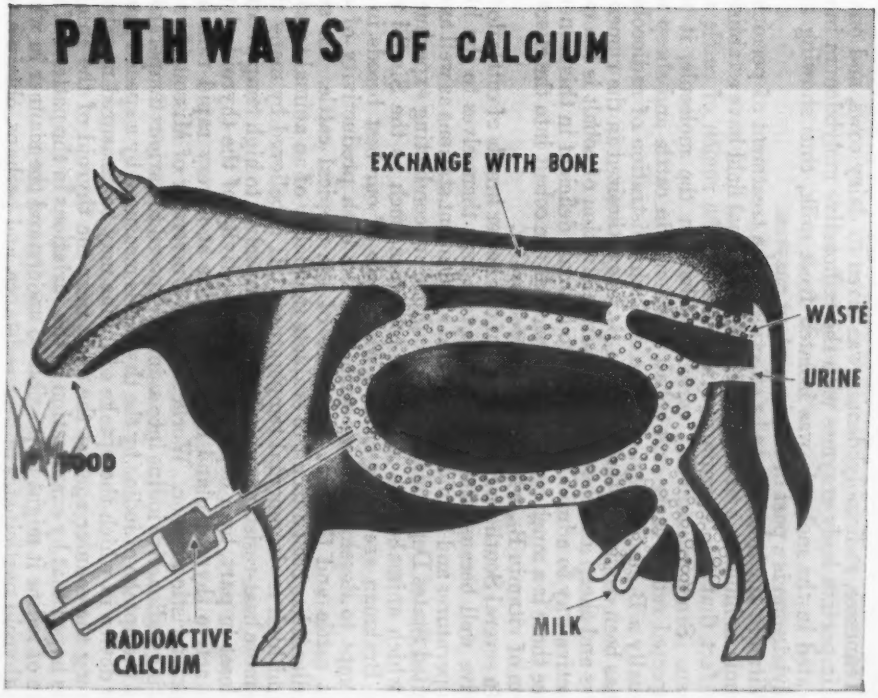

EXHIBIT 25.—Use of radioactive calcium to establish availability of calicum in the feed.

phorous in various feeds. For example, it was shown by California workers by this technique that while the apparent digestibility of the phosphorous of alfalfa hay for lambs was only 22 percent, the true digestibility was 91 percent, thus showing that alfalfa hay is an excellent source of phosphorous for the feeding of ruminants.

Another example of the use of radioistopes in animal studies is that showing that the mineral, molybdenum, is essential for animals. Prior to the work with radiomolybdenum, it had been assumed that this mineral was essential for plants but not for animals. In recent work at Tennessee, radiomolybdenum was given to dairy cows, and one of the important body enzymes with the radioactive molybdenum incorporated in the molecule was isolated from milk, thus showing that molybdenum is a part of this important enzyme.

Vitamin B_{12} is known to be effective in the treatment of pernicious anemia in humans, and researchers in the animal field have established the fact that this vitamin is synthesized in the rumen of cattle and sheep. Since vitamin B_{12} contains cobalt in the molecule, it was suspected rather early that cobalt deficiency in cattle and sheep was actually a B_{12} deficiency. By the oral administration of radiocobalt, it has been confirmed that vitamin B_{12} is synthesized in the rumen of cows and sheep and that the oral administration of cobalt is the most effective way to administer cobalt to animals deficient in this mineral, since there is a much greater conversion of the cobalt into the effective form of vitamin B_{12} when administered orally.

In several Southern States many of our better breeds of cattle do not thrive well because they are unable to adapt themselves to the high temperatures and humidity. Several experiment stations as well as the United States Department of Agriculture are conducting experiments in which animals with high-heat tolerance, such as the Sindhi and the Brahman are being crossed with some of our best breeds in an attempt to develop animals with both the high productivity of our best cattle and the heat resistance of the tropical cattle. In such studies it has been difficult to evaluate the ability of an animal to withstand high environmental temperatures. It is believed by many that the more heat-resistant animals adapt themselves to high temperatures, at least in part, by a depression in the activity of the thyroid gland. An active thyroid gland takes up iodine at a very rapid rate in a characteristic manner. Workers at the University of Missouri are injecting radioactive iodine into animals exposed to various temperatures and the uptake of iodine by the thyroid is measured by a special counting device in which the uptake of iodine may be measured merely by placng the counter against the neck, near the thyroid of the animal. It is hoped that by examination of the variations in the pattern of uptake of iodine it might be possible to understand the manner in which the thyroid participates in heat resistance, and perhaps, obtain a way of identifying the animals with more than average heat resistance for the purpose of breeding more heat-resistant animals.

Researchers at Cornell University have shown that the amino acids, cystine and methionine, are synthesized by sheep and cattle from radioactive inorganic sulfate administered orally. It was rather surprising when United States Department of Agriculture workers reported that the chicken could synthesize the amino acid, cystine, from inorganic sulfate. Radioactive sulphur was used in these studies. It was ob-

served that the amino acid cystine containing radioactive sulphur was incorporated into the protein in the feathers. The radioautographs show the location of radioactivity in the feathers. The observations made suggest that only the growing feather takes up methionine and/or cystine and that there is no exchange of these amino acids in the feather with those of the body. This work also demonstrated that growth takes place only from the base of the feather. Since cystine has a sparing effect upon methionine but cannot replace all of it in the diet, it is now apparent that inorganic sulfate must be considered as an important and cheap nutritional mineral even for nonruminants. Radioactive sulphur also offers excellent opportunities for the study of wool growth and the effect of nutrition upon the growth of wool fibers, the crimp of the wool, and the development of imperfections due to poor nutrition, since the growth of wool and the growth of feathers have much in common. In addition, radioactive sulphur is being used by Wyoming workers to study selenium poisoning. This is an extremely important problem, since many areas in some of our Western States have had to be abandoned because of the high content of selenium in the soil. This selenium is incorporated into the organic material of plants and when consumed by animals results in many toxic effects. Sulphur metabolism has been shown to be affected by the ingestion of selenium, and indeed appears to be interchanged with sulphur in the important amino acids, thus making these amino acids unavailable to the body. Thus, the metabolism of sulphur in animals suffering from chronic selenium poisoning is now being studied by radioactive sulphur, and should give us a better insight into the mode of action of selenium.

By the injection into cows of substances which contain radioactive carbon and then measuring the radioactivity of the expired carbon dioxide and of the various milk substances, we can establish the rate at which these substances are broken down within the body and to what extent the carbon in them contributes to the formation of milk substances. (See exhibit 26, p. 74.) By the use of such techniques, it has been shown by California workers and others that carbon dioxide, glucose, and acetic acid, and other substances are converted into various milk constituents. For example, radioactive glucose injected intravenously into the lactating cow is quickly converted into milk sugar (and other milk constitutents) as shown by the fact that milk sugar is highly radioactive following the injection of glucose. Such studies are extremely important in establishing the role of the body in the formation of milk from various nutrients.

In the rumen of the cow carbohydrates in the form of both starch and cellulose as well as protein are acted upon by micro-organisms and broken down into small molecules. The principal end products are acetic acid, propionic acid, and butyric acid, and these are absorbed into the body for metabolic purposes. Acetic acid is built into the body fats and other substances, used for energy, and has been shown by radioisotopic studies to be converted into milk fat. Propionic acid is converted into liver glycogen, and in the ruminant, butyric acid appears to be converted primarily into beta-hydrovybutyric acid.

When acetic, propionic and butyric acids containing radioactive carbon were injected into the cow, it was noted that 17 percent of the radioactivity from acetic acid, 11 percent from propionic acid, and

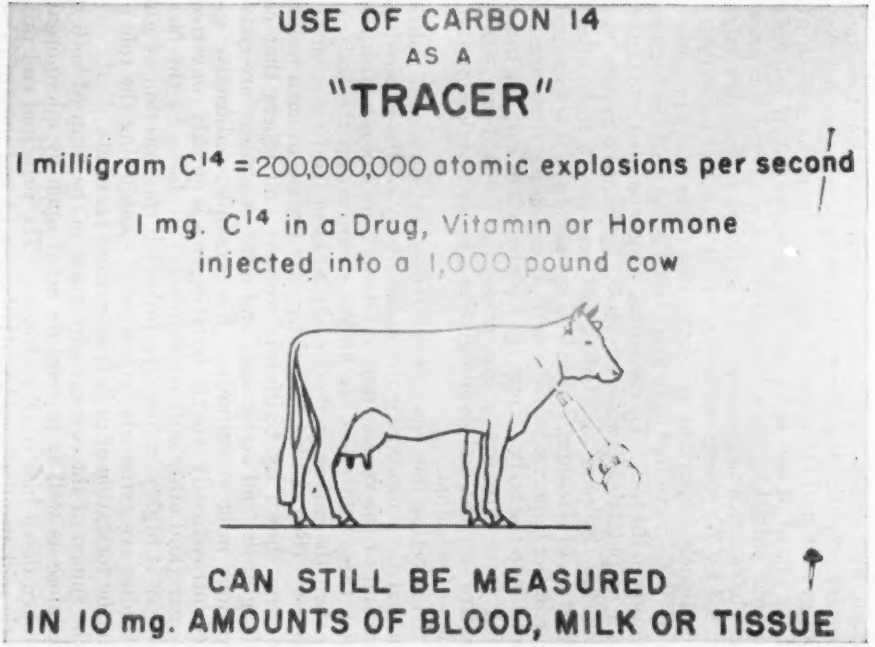
USE OF CARBON 14
AS A
"TRACER"
1 milligram C14 = 200,000,000 atomic explosions per second
1 mg. C14 in a Drug, Vitamin or Hormone
injected into a 1,000 pound cow
CAN STILL BE MEASURED
IN 10 mg. AMOUNTS OF BLOOD, MILK OR TISSUE

EXHIBIT 26.—Sensitivity of radioisotopic techniques in animal studies.

6 percent from butyric acid appeared in the milk, thus giving an estimation of their efficiency of transformation into milk. When glucose containing radioactive carbon was injected into the cow, 56 percent of radioactive carbon appeared in the milk. By analyzing the milk and studying the amount of activity found in each milk component, it is possible to show what milk substances arise from acetic acid, propionic acid, glucose, and butyric acid, and also suggest some of the pathways by which these transformations take place in the animal body.

In order to determine more precisely how the milk substances are produced from blood substances within the udder, an "artificial cow" is being used at Minnesota, Wisconsin, and at Maryland. (See exhibit 27, p. 76.) This apparatus consists of an artificial heart and lung by means of which blood is pumped through the isolated udder of a cow. Radioactive tracer substances are added to the blood and after pumping the blood through the udder for several hours, the udder is milked out with the aid of a hormone, the various milk components isolated, and the radioactivity of each determined. In such a study all of the metabolic reactions which occur take place in the udder, since there are no other organs in the system. Thus it is possible to establish more exactly the reactions which take place within the udder in the secretion of milk. For example, when radioactive glucose is injected into the blood stream of a cow it has been shown that while most of the radioactive carbon will be found in milk sugar, some will be found in other milk components. On the other hand, when radioactive glucose was pumped through the udder by the use of the artificial heart-lung apparatus all of the activity was found in milk sugar and practically none in the other milk components. The conclusion to be drawn is that when glucose is injected into the cow it is converted into various substances such as fat and protein and these substances are carried to the udder by the blood and converted into milk components. At the same time, a considerable amount of the glucose passes directly to the udder and it is converted into milk sugar. By the use of the artificial cow and radioactive glucose, it has been possible to show that the udder itself utilizes glucose for milk sugar production only.

At the University of Maryland, the heart-lung perfusion technique (artificial cow) has been improved greatly by our tracer team, and a recent study has been conducted with radioisotopes which gives us a new insight into the way milk fat is produced. It had been shown previously that acetic acid was converted into the short-chain fatty acids which are peculiar to milk fat and it had been proposed that acetic acid was the principal source of the short-chain fatty acids in milk fat. In our studies, we added radioactive beta-hydroxybutyric acid to the blood being pumped through the isolated udder by the artificial heart-lung apparatus. An analysis of the milk showed that most of the beta-hydroxybutyric acid was converted into the short-chain fatty acids and that from 2 to 2½ times more short-chain fatty acids are produced from beta-hydroxybutyric acid than from acetic acid. (See exhibit 28, p. 77.) This is particularly important in the cow because the blood level of beta-hydroxybutyric acid is relatively high at all times. The short-chain fatty acids of butterfat, which make up approximately 20 percent of the butterfat, are the ones which

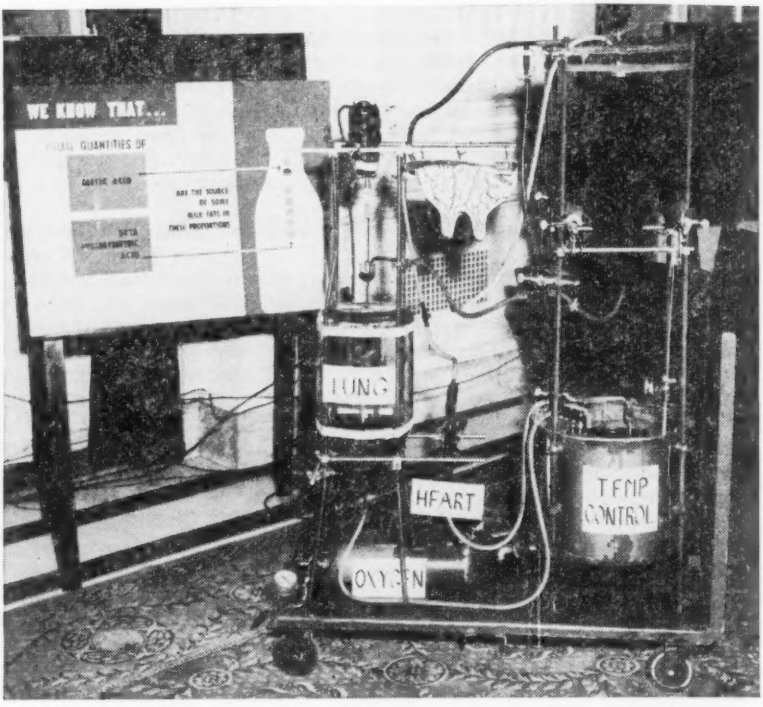

EXHIBIT 27.—Artificial cow for study of milk formation by use of radioisotopes (a fresh udder in this system forms milk).

give butterfat its unique characteristics as contrasted to other fats and oils. We have good reason to believe that the formation of the short-chain fatty acids of butterfat are associated with high milk and milk fat production and therefore the importance of this information is obvious.

Only a few selected examples of the use of radioisotopes in the studies of animals have been given, since time does not permit a review of all the work in this field. However, it is clear that by the use of radioisotopes we are now able to solve problems within a matter of weeks or months which otherwise would have required years, or would have been insolvable. The work done to date represents spade-work in a period of adjustment and it is to be expected that with the aid of radioisotopes, research developments in milk secretion and animal metabolism in general will proceed at a rate few could have conceived possible prior to the advent of such techniques.

Thank you very much.

Representative HINSHAW. Thank you, Dr. Shaw. Are there any questions? My friends and I unfortunately do not know enough about the mechanics of the cow to ask questions.

That is a very interesting demonstration that you have gotten together, Dr. Shaw, and we are greatly impressed with it.

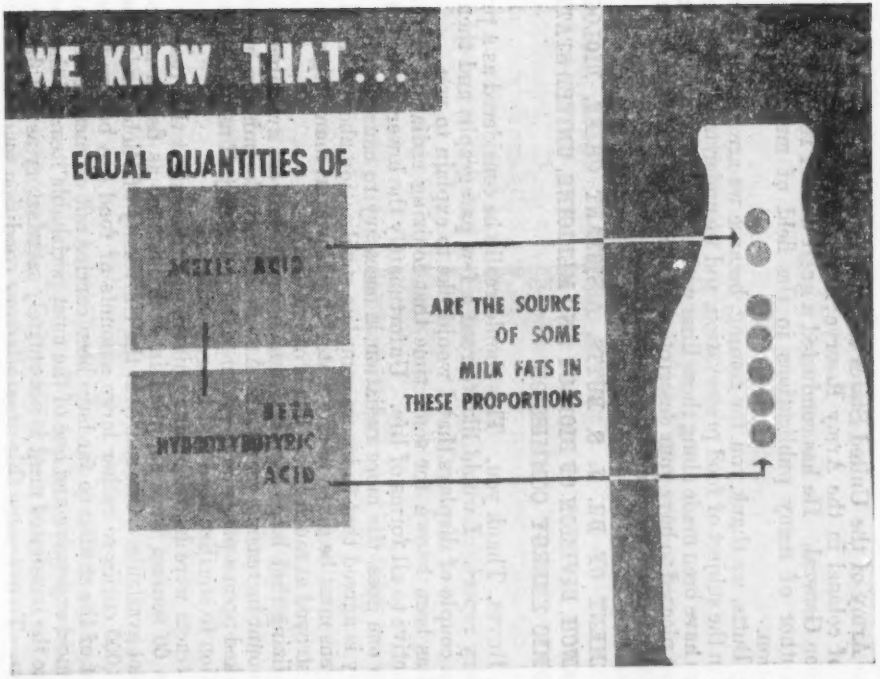
WE KNOW THAT...
EQUAL QUANTITIES OF
ACETIC ACID
BETA HYDROXYBUTYRIC ACID
ARE THE SOURCE OF SOME MILK FATS IN THESE PROPORTIONS

EXHIBIT 28.—New substances shown to be used in formation of milk fat by use of radioisotopes.

The next subject is Food Preservation, by Dr. J. S. Butts, Assistant Chief, Biology Branch, Division of Biology and Medicine, United States Atomic Energy Commission.

He is on leave from Oregon State College as head of the department of agricultural chemistry at that college. He took his bachelor of science degree at the University of Florida, his doctorate in philosophy at the University of Southern California. He was an associate professor of the Medical School of Southern California in 1939, past doctorate fellow at the University of Leipzig in 1938 and 1939; served in the Army of the United States from 1942 to 1946. He holds the rank of colonel in the Army Reserve; assigned to the Office of the Surgeon General. He has conducted a great deal of research, and is the author of many publications in the field of metabolism and nutrition.

Dr. Butts, we thank you for coming, because we are greatly interested in the subject of food preservation, and we understand that great strides have been made along those lines with the aid of atomic energy. We are pleased to have your description of that subject for our record, and for what use may be made of that record.

STATEMENT OF DR. J. S. BUTTS, ASSISTANT CHIEF, BIOLOGY BRANCH, DIVISION OF BIOLOGY AND MEDICINE, UNITED STATES ATOMIC ENERGY COMMISSION

Dr. BUTTS. Thank you. This should really be considered as a preliminary report. I would like to read a few paragraphs and then I have a couple of displays that I would like to explain to you.

It has been known for some time that ionizing radiation is very destructive to all forms of life. Unfortunately the lower in the scale of life one goes, the more radiation is necessary to cause death. It usually is agreed that to insure complete sterilization about 2 million roentgens must be given to any material. However, many organisms are destroyed at much lower levels of irradiation.

Realizing that large stores of fission products were available with the amount increasing yearly, the Atomic Energy Commission in 1952 embarked upon a program to evaluate the possibility of using ionizing radiation to sterilize food and pharmaceuticals.

Contracts were let with four universities to conduct this research. Cobalt 60 sources were supplied in each instance as fission sources were not available. One source at the University of Michigan is more than 3,000 curies so rather large amounts of food can be irradiated.

Most of the studies so far have been carried out on meat, since this is the most expensive and one of the most perishable items of the diet. To date the irradiated meat is not entirely satisfactory as "off flavors" develop. To overcome this unsatisfactory condition many materials, as ascorbic acid, are being added to the meat before irradiation to counteract the development of undesirable changes. These materials do help, but no one compound has given complete protection.

One phase of this program is especially promising. That is the "pasteurizing" of meat. At present prepackaged meats have a shelf life of about 3 or 4 days. When packaged and irradiated this shelf life is extented 2 weeks or more. The level of irradiation is much below the range needed for sterilization. Usually about 20,000 roent-

gens is the amount given so the undesirable changes are kept at a minimum.

Representative HINSHAW. Twenty thousand roentgens over what period of time?

Dr. BUTTS. Over a total dose. It might be given over a very short time or a very long time. It apparently does not make much difference. So if you have a very high source of irradiation, it might be done in a few minutes or if you have a relatively low one, it might take an hour. It does not seem to make any difference.

Representative HINSHAW. Twenty thousand roentgens is a great many roentgens.

Dr. BUTTS. That is right. It is in terms of what you or I might be able to take, but it is not very much when you consider the strength of some of our sources. It can be given in very short order.

Representative HINSHAW. I understand so, but it is something like 40 times the lethal dose, is it not?

Dr. BUTTS. Yes; that is right, at least 40 times.

It has been shown that the irradiation of pork breaks the trichinosis cycle and food that has received 12,000 roentgens is entirely safe to eat. If radiosterilization is used this destruction of the trichinae larvae is an additional advantage.

At Brookhaven National Laboratory potatoes were subjected to irradiation. Those irradiated in December 1952 and stored under commercial condition are in excellent condition while the potatoes not irradiated are completely worthless.

I actually have two samples I would like to show you. These are also pictures. (See exhibit 29, p. 80.) This is the potato which was irradiated, and this is the control which has not received any irradiation.

Representative DURHAM. Were they under identical storage conditions?

Dr. BUTTS. Yes, sir. You can see this was obviously the one irradiated with 20,000 r, and this is the one that was not irradiated.

I believe that the enzyme systems which cause the breakdown of the starch to the soluble sugar is destroyed in this potato whereas they are available to carry on the hydrolytic processes in the unirradiated potato.

Representative HINSHAW. Will you say that again?

Dr. BUTTS. The sugar which is stored in here is largely in the form of starch. As germination occurs this starch breaks down into the soluble sugar.

Representative HINSHAW. In the germination of the potato?

Dr. BUTTS. That is right. It apparently takes enzymes to break the starch down into sugar. Apparently those enzymes are destroyed. These enzymes are inactivated in this potato so that they are not effective. The starch would be hydrolyzed to sugar concurrently with the sprouting. That is the theory which has been put forward, anyway. It has only been tried out on two vegetables. Whether it will work on others, we do not know.

Representative DURHAM. Have you tasted those to see if there is a change in taste?

Dr. BUTTS. Yes; they have been tasted and they are entirely satisfactory to eat.

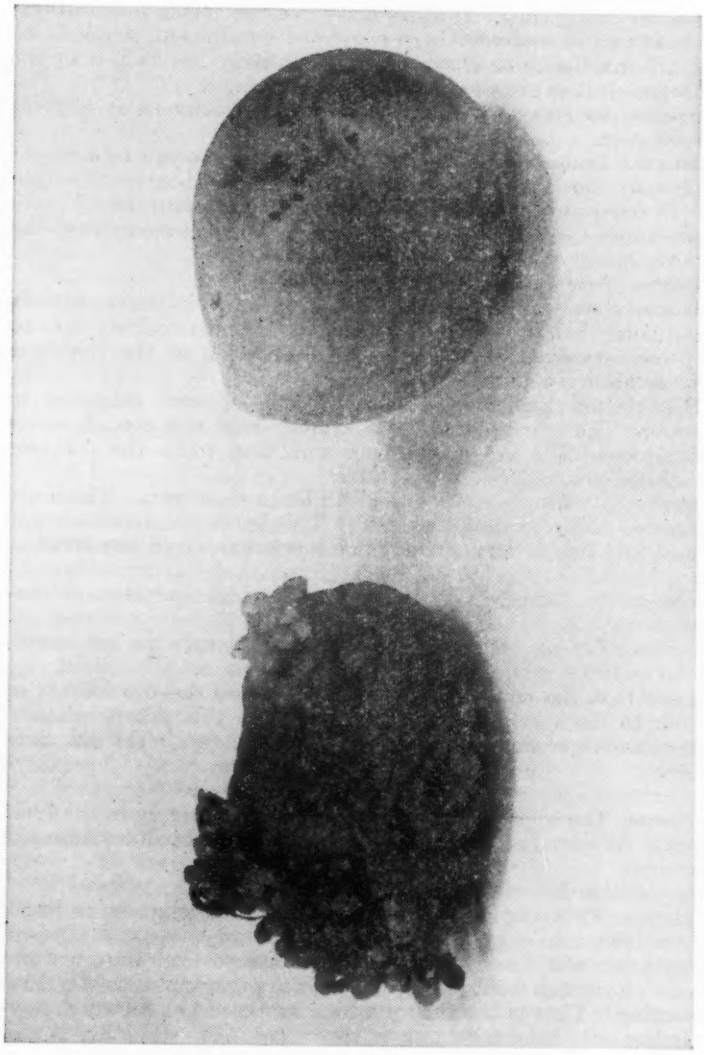

EXHIBIT 29.—Potato on right subjected to 20,000 r cobalt–60 irradiation December 1952. Potato on left nonirradiated. Both samples held under commercial conditions of storage since that time. Picture taken on March 18, 1954.

The only other vegetable which has been included in this study are onions. The University of Michigan has reported this works equally well with onions. These are the only vegetables in which this has been tried.

The pioneering studies of the AEC have shown considerable promise. Consequently, the Quartermaster Corps has embarked upon a 5-year program in food sterilization and is expecting to invest $6 million. Although the Quartermaster will take over most of the present AEC contracts at the end of fiscal year 1954 and greatly implement the program, this does not mean that the AEC will lose interest in the program, but rather that our interests will be directed toward another phase of the problem, namely, the fabrication of sources of fission products to be made available for such studies.

Representative HINSHAW. Let me get this straight. You say the Quartermaster General is taking over the program. In other words, they are going to pay for it and conduct it.

Dr. BUTTS. Yes; for the major part of the program.

Representative HINSHAW. Therefore, it gets out of the hands of the Atomic Energy Commission.

Dr. BUTTS. Not entirely.

Representative HINSHAW. I am very much interested, because I would like to find out whether the program under the military is to furnish material in the nature of instructive papers and so forth which are equally available to the public, or whether they will mark the things "top secret" so that they will not be available to the public.

Dr. BUTTS. They have assured us that any results which come from this study will be published in the open literature.

Representative HINSHAW. And promptly.

Dr. BUTTS. Promptly. They have assured us of that. I believe this will be followed through on because I happen to know quite a few of the groups that will be conducting these studies, and they would not accept the contracts under any other circumstances.

Representative HINSHAW. They are to be conducted by civilian groups under Army contracts.

Dr. BUTTS. Yes.

Representative HINSHAW. I understand now. They are not to be conducted behind closed doors as is most of the work of the military in the atomic-energy field.

Dr. BUTTS. That is right. This is going to be done in universities. There will be some 10 or 15 universities throughout the country that the Army will give these contracts to, and these contracts will be carried out and the results will be published in the open literature.

Representative HINSHAW. Of course, we understand the need for food preservation that the military has.

Dr. BUTTS. That is right. They are hoping to get away from refrigeration or at least minimize it. That is the long-range objective.

To show that the Atomic Energy Commission is not entirely losing their interest in this, to continue with my statement, this in itself is a major research program when it is considered that geometry, dosimetry at very high levels, energy spectrums, and types of fission products must be evaluated. To date one design of a fission product source has been fabricated and sent to MIT. No reports on its use

have been received yet, as the fission source was just sent up 3 weeks ago.

I might show this chart. This is the first one that has been constructed. The fission products were concentrated as far as they felt it was really safe to go. The fission product is a small container inside of this shielding, and it is in the form of a concrete block. This was a semiliquid material which was mixed with cement and a hollow cylinder was made about 5½ inches in diameter with a hollow center so a small can, about 14 inches long, can be slipped in. That is inside this container which has the shielding. We do not know how well this is going to work out because, as I say, this is the first time this has been attempted. We are awaiting with great interest the results that Dr. Proctor and his group may attain.

Since large amounts of irradiated foodstuffs are needed in this accelerated program, arrangements have been made to irradiate the food at the material testing reactor at National Reactor Testing Station. Fuel elements will be used as a source of ionizing radiation. We do not have the fission product sources fabricated. It is, of course, expected that before too long suitably designed fission product sources of high intensity will be available.

That is about the story to date. The program shows real progress. We have not been at this long enough. The Quartermaster is just starting. They have no contracts to date. I guess the 1st of April was the effective date of the first contracts. So you see they are just getting under way in this.

The program holds promise, but no one knows whether or not we will be able to eliminate these off flavors and undesirable side effects which do occur.

That is about the story, Mr. Chairman.

Representative DURHAM. Could this work, Doctor, be done in an ordinary type reactor? Would it have to be changed?

Dr. BUTTS. I did not understand you, sir.

Representative DURHAM. How would this radiation take place? Would you do it in a reactor?

Dr. BUTTS. It could be done in a reactor, and it is visualized that if this program goes forward the way it may and if reactors are built, we will have a very large source of ionizing radiation that could be used. However, we can use cobalt 60.

Representative DURHAM. I was thinking about the expense of it.

Dr. BUTTS. It would not be practical with cobalt 60, that is true.

Representative DURHAM. I should think not.

Dr. BUTTS. What we hope is that these fission products can be worked into this program.

Representative HINSHAW. That is, the fission products of the pile?

Dr. BUTTS. Yes; that is right.

Representative DURHAM. That is a little clumsy, compared with building and using an ordinary reactor for radiation.

Dr. BUTTS. That of course is a possibility and that has been suggested. I think perhaps in the future if this method of sterilization proves feasible that is not beyond the realm of possibility that it might be worthwhile. We do not know yet. It is much too early to think in terms of a reactor, in my opinion.

Representative HINSHAW. A reactor would be quite an expensive undertaking.

Representative DURHAM. I was just thinking about those that we have been building around the country.

Dr. BUTTS. As a byproduct they can be used.

Representative HINSHAW. They will be built as research tools here and there, but the use of the fission products, following their inclusion in the fuel, is probably a good use of that material and a very economical source of radiation.

Dr. BUTTS. That is right.

Representative DURHAM. Have you tried it out on meat yet?

Dr. BUTTS. Yes, sir. That is the material which has been studied most extensively. Although the meats are palatable, there is some off flavor to them.

Representative DURHAM. Over how long a period?

Dr. BUTTS. The off flavor lasts indefinitely. There is some really fundamental change that occurred in the protein.

Representative HINSHAW. Do they occur immediately upon irradiation?

Dr. BUTTS. Yes, sir.

Representative HINSHAW. And then stay with the meat product for all time?

Dr. BUTTS. That is right. But by adding some of these materials such as ascorbic acid that I mentioned, these off effects can be minimized very much. I have seen some samples which were really quite good. But they are not as good as the unirradiated. I must say.

Representative HINSHAW. Nevertheless, they do afford a perfectly good although not customary taste as a protein source of diet?

Dr. BUTTS. That is right.

Representative HINSHAW. And for how long?

Dr. BUTTS. On these prepackaged meats, such as you see in some of the food counters where they are being held at low temperatures, that is, above freezing, normally these meats cannot be held more than 2 or 3 days. But after radiation the meats may be held for 2 weeks and in some cases 3 weeks. There is very little off taste in these because the level of irradiation is not so high.

Representative HINSHAW. What about the preservation as to large numbers of months?

Dr. BUTTS. I do not believe anybody can answer that yet. I do not believe any meat products have been radiated and preserved for that length of time.

Representative DURHAM. It has been done?

Dr. BUTTS. It has been sterilized. There is no doubt about it. That is true. The material is sterile. There is no doubt about it.

Representative DURHAM. That means a lot if you can replace something like K rations. It could not taste worse than K rations.

Dr. BUTTS. That is right.

Representative DURHAM. That is a very interesting presentation, Doctor.

Representative HINSHAW. I am informed by a member of our staff that there is contained in a record made by the forum conducted in New York the fact that by the year 2000 A. D., assuming 20 percent of the United States' electric power comes from nuclear reactors,

enough fission-product radioactivity will be available annually to sterilize three times the annual United States food supply.

Dr. BUTTS. I had not seen those figures.

Representative HINSHAW. That is contained, they say, in the record of the Brookhaven National Laboratory experiments and the symposium connected therewith.

That is very interesting, Doctor. We are very happy to have it. We are happy to have you to come to us.

Are you stationed here in Washington, Dr. Butts?

Dr. BUTTS. Yes, sir; I am until the end of the summer. I return to Oregon State College at the end of the summer.

Representative HINSHAW. You will be right close to home, then.

Dr. BUTTS. Yes, sir.

Representative HINSHAW. We thank you very much.

That will conclude the hearings, with a great deal of appreciation to Dr. Bugher, Dr. Pearson, and their associates, for appearing here and putting together a record which we are quite certain will be of value to the Members of Congress, and through them disseminated to all parts of the United States. I am sure that will incite an interest which will be lasting and fruitful. We thank you.

(Thereupon, at 4:10 p. m., the hearing was concluded.)

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